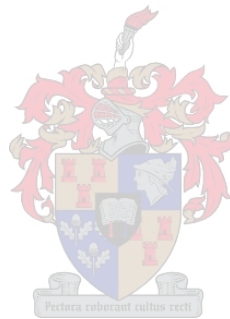


The financial implications of endemic stability as a control strategy for Bovine babesiosis in veld grazing beef production systems of the KwaZulu-Natal Midlands

by

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*Dedicated to my father, Owen Edwardes.
Inspired by my grandfather, Jean Allain Lalouette.*

Declaration

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Abstract

The consumption of beef products in South Africa is expected to increase by 24% in the next ten years. To achieve the production levels, efficiency need to be optimised. Production challenges arise as a result of climatic changes, policy implementations, pests and production diseases of which the myriad of tick-borne diseases present in South Africa form a large component. One of the most economically important tick-borne disease is Bovine babesiosis and has carried this label for at least 35 years. Despite its importance, little economic research was conducted within South Africa borders.

Bovine babesiosis is caused after a tick vector, either *Rhipicephalus decoloratus* or *Rhipicephalus microplus*, transmits a *Babesia bigemina* or the more virulent *Babesia bovis* parasite to a susceptible bovine. Infection may result in direct production losses such as mortality and weight loss, indirect production losses such as abortions and reduced fertility which are all translated into revenue forgone. Expenditures incurred due to preventive and treatment measures as well as maintenance costs such as compensatory feed.

The concept of endemic stability whereby little to no evidence of clinical disease occurs, has long been an epizootiological principle discussed as a control strategy for Bovine babesiosis. To achieve endemic stability, a strategic dipping routine is implemented exposing cattle to a tick challenge in order to promote the development of endemic stability through parasite transmission.

Farmers shifting from intensive dipping towards the strategic option is encouraged by veterinarians, but little is known about the economic and financial implications. This study attempts to fill this gap in the knowledge by exploring the financial and economic implications of either prevention method within beef farms of KwaZulu-Natal Midlands. This was achieved by developing a dynamic stochastic model which simulates a stable herd of 100 cow-spaces over a period of 15 years.

Scenarios at varying seroprevalence rates were simulated to compare the economic impact incurred for either dipping strategy, to analyse the results financially, and therefore provide insight as to whether a farmer should focus on maintaining the intensive dipping option or to promote the development of endemic stability. Extreme intensive dipping in the attempt to eradicate tick-vectors is not in the scope of this study.

Results indicate that *Babesia bovis* infections are a cause for greater concern as it may translate into damages up to twenty-fold the economic impact of *Babesia bigemina*. Overall results indicate that intensive dipping results in a smaller economic impact than strategic dipping except in a scenario of 90% *Babesia bigemina* seroprevalence. The value of weight lost is responsible for

the largest component of the total economic cost. Financial indicators determine that intensive dipping is the more feasible method of prevention for all simulated scenarios of either parasite except for where a 90% *Babesia bovis* seroprevalence exists. With decreasing seroprevalence rates, the economic consequences decrease while the NPV and IRR increase for an intensive dipping strategy suggesting that the eradication of tick vectors in the attempt to achieve a disease free situation should result in greater production efficiencies.

Opsomming

Die verbruik van beesvleis produkte in Suid-Afrika sal na verwagting met 24% toeneem oor die volgende tien jaar. Om die nodige produksievlakke te bereik sal doeltreffendheid van produksie moet toeneem. Produksie uitdagings kom voor weens klimaatsveranderings, beleid implementering, peste en plaë, waarvan die verskeidenheid bosluis oorgedraagde siektes in Suid-Afrika 'n groot komponent uitmaak. Een van die ekonomies belangrikste bosluis oorgedraagde siektes, reeds vir 35 jaar, is Bovine babesiosis. Ondanks die belangrikheid daarvan is daar beperkte ekonomiese navorsing op die siekte binne Suid-Afrika gedoen.

Bovine babesiosis word veroorsaak deur 'n bosluis vektor; of *Rhipicephalus decoloratus* of *Rhipicephalus microplus*, versprei *Babesia bigemina* of die meer kwaadaardige *Babesia bovis* parasiet na 'n vatbare gasheer. Infeksie kan produksie verlies tot gevolg hê, soos gewigsverlies en laer vrugbaarheid en abortering wat direkte finansiële verlies veroorsaak. Koste kan verhoog weens voorkomende en onderhoudende aksies soos dip en spuit programme en byvoeding.

Die konsep van endemies stabiliteit waar geen of min voorkoms van kliniese siekte sigbaar is, word lank reeds as 'n klinies dierkundige beginsel bespreek as beheer strategie vir Bovine babesiosis. Ten einde endemiese stabiliteit te bereik word 'n strategiese dip program gevolg wat beeste blootstel aan bosluis besmetting om die weerstand teen infeksie deur parasiet oordrag te verhoog.

Produsente van oorsakel van die intensiewe dip opsie na endemiese stabiliteit word deur vee-artse ondersteun, maar daar is min kennis aangaande die finansiële implikasies. Die studie poog om hierdie gaping te vul deur die finansiële implikasies te ondersoek van beide beheer maatreëls op plaasvlak in die KwaZulu-Natal Middellande. Die doel is bereik deur die ontwikkeling van 'n dinamiese stochastiese model wat 'n stabiele kudde van 100 beeste oor 15 jaar simuleer. Scenario's teen verskillende weidingsvoorkoms koerse is gesimuleer om die impak te vergelyk van die verskillende dip strategieë. Die resultate verskaf insig in die opsie om intensief te dip of oor te skakel na strategiese dip met gepaardgaande endemiese stabiliteit opbou. Ekstreme intensiewe dip, as strategie om van die bosluis as draer uit te roei, was nie deel van die omvang van hierdie studie.

Resultate wys dat *Babesia bovis* infeksie groter gevaar inhou as *Babesia bigemina* en skade kan soveel as 20 keer meer wees in finansiële terme. Algehele resultate wys dat intensiewe dip 'n kleiner finansiële impak het as strategiese dip, behalwe vir die scenario waar 90% van die bosluis populasie *Babesia bigemina* is. Die waarde van gewigsverlies is die grootste bydraer tot algehele finansiële impak. Finansiële indikasies wys dat intensiewe dip die meer lewensvatbare opsie is vir alle scenario's, behalwe waar 90% *Babesia bovis* voorkoms is. Teen laer bosluis voorkoms koerse verlaag die NHW (netto huidige waarde) en die IOK (interne opbrengskoers van kapitaal investering) vir 'n intensiewe dip strategie wat sinspeel daarop dat die uitwissing van die bosluispopulasie ten einde

infeksie te verlaag die mees doeltreffende strategies behoort te wees.

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List of Abbreviations

AHE	Animal health economics
IRR	Internal rate of return
NPV	Net present value
syn.	synonymous

Chapter 1

Introduction

1.1 Background

Planet earth is experiencing increasing trends in the number of human inhabitants and by the year 2050 the population is expected to reach a figure between eight and eleven billion (Gerland, Raftery, Ševčíková, Li, Gu, Spoorenberg, Alkema, Fosdick, Chunn, Lalic, Bay, Buettner, Heilig, and Wilmoth, 2014). A growing human population results in increasing trends of food consumption. For example, between 1950 and 2010, an increase in global meat consumption has been recorded where by the global production of beef rose by 232% (EPI, 2013a). On the African continent the human population has increased by 248% and is coupled with an increased number of livestock of 156% (EPI, 2013b), between the years of 1960 and 2010. This suggests that the increased population of domestic animals contributes to a rise in the consumption of beef products. In the case of South Africa, cattle production has increased by 46% in 2014 compared with 2005. Local consumption trends indicate that the country is a net importer of bovine meat products, due to the supply not capable of meeting demand requirements (DAFF, 2015). The country's projected population growth of 1.2% (Stats SA, 2017) and the expected rise in beef consumption by 24% over the next ten years (BFAP, 2018) will require farmers to produce at greater efficiencies to meet local demand and to reverse the trade role it currently finds itself in. However, agricultural production comes with many challenges. Production diseases, such as the myriad of tick-borne diseases, are partly responsible for the challenges agriculturalists face. Amongst these, bovine babesiosis is considered as one the greatest economically important tick-borne diseases in South Africa (Spickett, 2013:25).

The first recording of bovine babesiosis occurred before the identification of its cause in 1970 when it was noticed along the coast of what is now known as KwaZulu-Natal near the Tugela river mouth. However, it was recognised by the Zulus that the disease occurred in Zululand and Swaziland before it was first recorded (Theiler, 1905; Henning, 1949:371). Today, *Babesia bigemina* is known as an indigenous parasite (de Vos, de Waal, and Jackson, 2004:406). *Babesia bovis* was identified with certainty in South Africa by Neitz (1941) and is believed to have been introduced by its only known vector, *Rhipicephalus microplus*, in the late 1800's (Potgieter, 1977; Spickett, 2013:25).

The distribution of the parasites are directly related to the distribution of their vectors; *Babesia bigemina* has a greater distribution than that of *Babesia bovis*. *Babesia Bigemina* is found in all of South Africa except for the arid areas such as the Northern Cape and Great Karoo. *Babesia bovis* occurs in most of Limpopo, KwaZulu-Natal, Mpumalanga, Gauteng and along the Eastern and Western Cape coast (du Preez and Malan, 2015; de Vos, 1979). Further accounts of the parasites' distribution can be reviewed in Regassa, Penzhorn, and Bryson (2003); Rikhotso, Stoltz, Bryson, and Sommerville (2005); Terkawi, Thekiso, Katsande, Latif, Mans, Matthee, Mkize, Mabogoane, Marais, Yokoyama, Xuan, and Igarashi (2011); and the monthly reporting of African and Asiatic bovine babesiosis in RuVasa (2017). Only one study has reviewed the prevalence of *Babesia bigemina* and *Babesia bovis* on commercial farms in the area of study, however, the article is outdated (de Vos, 1979). In a more recent study, Hesterberg (2007) explores the prevalence of the parasites in KwaZulu-Natal, but more focus was placed on the rural areas rather than commercial farms.

Primary transmissions of *Babesia bigemina* in cattle older than nine months are less virulent when compared with *Babesia bovis*. However, production losses can occur in the form of mortality, weight loss and abortions by varying degrees for either parasite (Bock, Jackson, de Vos, and Jorgensen, 2004). These losses coupled with treatment and prevention expenditure can result in significant costs for a farmer. Prevention methods include a combination of acaricides, and the various dipping schedules (Smith, Evans, Martins, Cereser, Correa, Petraccia, Cardozo, Solari, and Nari, 2000), attenuated live vaccines (de Waal and Combrink, 2006), and vaccines administered to cattle preventing the engorging of ticks such as GavacTM. A prevention strategy that has long been discussed is to apply the concept of endemic stability (Mahoney, 1974). This means that the cattle are provided the opportunity to take advantage of their non-specific immunity through less aggressive tick eradication methods in order for herd resistance to develop over time.

1.2 Problem statement and research question

Bovine babesiosis is considered a globally important disease (Jongejan and Uilenberg, 2004) and is one of South Africa most economically pertinent tick-borne diseases (Spickett, 2013:25). However, no conclusive literature has been published regarding the economic impact caused by bovine babesiosis in South Africa. It is common knowledge amongst all stakeholders of the South African beef and broader cattle industry that bovine babesiosis, caused either by *Babesia bigemina* or *Babesia bovis*, is indeed a serious problem concerning production; a problem that is not new, but has rather been known of since at least the early 1980's (de Vos, de Waal, and Jackson, 2004). If bovine babesiosis is regarded with such high economic importance, why has there been little economic or financial research conducted internationally? Furthermore, why has South Africa not conducted exploratory economic or financial research studies in the last 35 years in an attempt to address this concern? The concept of developing a state of endemic stability through less aggressive acaricide applications is an intervention which has been suggested and is slowly implemented by the countries farmers, but no economic and financial insight is provided to those who implement this method of control.

The main research question for this study is; what is the value of adopting a strategic dipping option in an attempt to promote the development of endemic stability compared with an intensive acaricide treatment routine? By doing so, this study asks a question pertaining to

the economic impact and financial implications of developing endemic stability by implementing a strategic dipping intervention. The study will be conducted at the herd level within the KwaZulu-Natal Midlands and is compared with an intensive dipping approach.

1.3 Research objectives

Section 1.2 highlights the need for economic and financial research to be conducted in the realm of bovine babesiosis. The main aim of this study is to explore the value of adopting a strategic dipping option in an attempt to promote the development of endemic stability compared with an intensive acaricide treatment routine. This exploratory research should provide estimates identifying the economic consequences and financial implications of bovine babesiosis at the herd for either dipping strategies. Resultantly, the following objective should provide insight to cost-effective decision-making regarding prevention options in terms of financial viability. A comparison of intensive dipping and the largely discussed concept of creating endemic stability is conducted. The study will consider the infections of *Babesia bigemina* and *Babesia bovis* parasites in *Bos indicus* cross *Bos taurus* cattle breeds. The study focuses on the herd level of a typical commercial veld grazing production system in the KwaZulu-Natal Midlands.

The goal of the research objective is to establish a set of principles enabling further economic and financial research to be pursued. To achieve this goal, specific sub-goals of the research were set:

1. Develop a model which can provide an estimate of the economic impact and financial implications of bovine babesiosis has at the herd level of a typical farm in the KwaZulu-Natal Midlands with the available data and existing research efforts
2. Financially compare the established dipping strategies of the KwaZulu-Natal Midlands as a result of the developed model highlighted in Point 1
3. Establish factors in which data relevant to the research problem is scarce or non-existent encountered through the development of the model as in Points 1 and 2
4. Establish the need for correct data collection by farmers when confronted with an infected animal in relation to Point 3
5. Suggest methods of data collection in relation to Points 3 and 4 and further research opportunities in order to develop more accurate estimates of cost-effective management options.

1.4 Research methodology

In order for the primary objective to be achieved, the correct factors concerning the economic and financial impact that a disease may have on livestock production will be established through a literature review of the Animal Health Economics (AHE) discipline. Building on the establishment of this, factors concerning the production effects of bovine babesiosis will be addressed. The establishment of the factors will in turn allow for financial comparisons of either

dipping strategy and the resultant production effects. Using R Studio (RStudio Team, 2016), a dynamic stochastic model is developed to simulate on farm activities with direct relation to the production of beef weaners intended for sale. Production at a steady state or disease free situation is then available for simulation where revenues and expenditures are recorded. Varying rates of *Babesia* seroprevalence (simulation scenarios) are introduced to the simulation of production where the resultant production effects are recorded and are translated into monetary values. The production effects included are the result of important factors established in the existing literature. Published data, validated by experts in the KwaZulu-Natal, are incorporated as input parameters. Expert opinion is provided through semi-structured interviews where a lack in published data exists. Furthermore, the cost of intervention and treatment are also included. The model is simulated for a prescribed number of years in order to promote the development of endemic stability in strategic dipping scenarios. Intensive dipping scenarios are simulated for an equal number of years. Economic consequences and financial indicators, the net present value and the internal rate of return on capital, are then compared between the two dipping strategies in order to determine the more feasible option, respective of parasite seroprevalence scenario.

1.5 Research outline

An overview of bovine babesiosis is provided in Chapter 2 in order to equip the reader with an understanding of the disease and relative factors as well as its complexity. In turn, the reader will have the knowledge to understand the distribution, habitat and the resistance cattle have to the tick vectors; the physical and transmission differences between *Babesia bigemina* and *Babesia bovis* as well as their respective life cycles; the resistance different cattle breeds show due to infection and the concept of endemic stability; clinical signs; diagnostic and treatment techniques; and the various prevention strategies implemented in practice.

Chapter 3 explores the literature highlighting the economic importance of bovine babesiosis at an international and national level. It further reviews the literature concerning the AHE discipline in order to discover existing frameworks which have been developed to assess the economic impact of production diseases. This is done in light of adopting and adapting these frameworks in order to fit the needs of this research. It is followed by identifying the important factors concerned with the production effects of livestock diseases that research should consider when conducting economic impact studies. Where possible and in line with the important factors, literature pertaining to the production effects of bovine babesiosis is included. The subsequent section follows the same format but is concerned with the treatment and prevention effects of production. The final section reviews existing peer reviewed publishings in relation to the economic and financial management of tick-borne diseases.

Chapter 4 presents the development of the model that measures the expected financial outcomes. Primarily, the definition of systems modelling, typical farm theory, the development phase and the general assumptions assumed are presented. The description of the model construction is separated into four subsections. The first is concerned with developing the production process and farm activities concerned with the rearing of beef weaners. The second involves attaching monetary values to the process and activities. In the third subsection, the process of infection, subsequent states of disease and the production effects are incorporated. The fourth subsection attaches monetary values to the production effects. All four components of the model contribute

towards identifying the economic impact and financial implications of either dipping strategy the study is concerned with. Furthermore, this chapter includes sections which describe the characteristics of a typical farm in the KwaZulu-Natal Midlands, it defines the dipping strategies, presents the simulation scenarios, it describes data collection methods and how the data was incorporated within the model as input parameters. The chapter is concluded with sections describing the method of evaluating the economical impact and financial analyses as well as important parameters that were changed for the sensitivity analysis.

Chapter 5 presents the results of the simulated scenarios of either parasite infection for each dipping strategy in two parts. First the physical results concerning the herd composition and the number of animals sold are presented. Secondly, the economic impacts and financial analyses of either dipping strategy are presented. The chapter is concluded with sensitivity analysis results.

The study is finally concluded with Chapter 6. In this chapter final conclusions, a summary and further recommendations are provided.

Chapter 2

An overview of bovine babesiosis

2.1 Introduction

"A knowledge of the epizootiology of tick-borne diseases is of fundamental importance for their effective control. It is only by understanding how the different pathogens are transmitted, what factors influence transmission, and in what ways the animal defends itself against the clinical effects of infection that one can hope to devise successful methods of disease control" (Bram and Uilenberg, 1983).

The main aim of this research is to explore the value of adopting a strategic dipping option in an attempt to promote the development of endemic stability compared to an intensive acaricide treatment routine. Chapter 2 provides an overview of bovine babesiosis. The overview equips the reader with important factors to account for in the attempt of establishing a control strategy by developing endemic stability. Topics such as the description, distribution and life cycle of the *Babesia* parasites and the tick vectors; parasite transmission; cattle resistance to the tick vectors; and the clinical signs of an infection, diagnosis and treatment methods are presented. Attention is drawn to the immunity of a cow once infected with a *Babesia* parasite; the epidemiological term of endemic stability with reference to bovine babesiosis; the inoculation rate; and dipping strategies that have been defined in the literature. The latter sections are of importance in this paper since detail is drawn from them for the development of the model described in Chapter 4. Furthermore, it must be noted that the tick species responsible for the transmission of the *Babesia* parasites belonging to the genus *Boophilus* have been reclassified to *Rhipicephalus* (Horak, Camicas, and Keirans, 2002). The tick vectors will be referred to their current classification throughout this thesis.

2.2 The *Babesia* parasites

The *Babesias* are protozoan parasites which belong to the phylum Apicomplexa, class Sporozoasida, order Eucoccidiorida, suborder Piroplasmorina and family Babesiidae (Levine, 1971). Of the eight existing parasites known to affect cattle (Figuerola, L'Hostis, and Camus, 2010:1821),

Babesia bigemina, *Babesia bovis* (syn. *Babesia argentina*; *Babesia berbera*; *Babesia colchica*) and *Babesia divergens* (syn. *Babesia caucasica*; *Babesia occidentalis*; *Babesia karelica*), are the most pathogenic and globally economic important parasites to cause bovine babesiosis (Bock, Jackson, de Vos, and Jorgensen, 2004; de Castro, 1997; Figueroa, L'Hostis, and Camus, 2010:1820; Jongejan and Uilenberg, 2004; de Vos, 1991). Other known *Babesia* parasites and their geographical distributions can be reviewed in Figueroa *et al.* (2010:1821). *Babesia occultans*, the cause of benign bovine babesiosis (de Vos *et al.*, 2004:7, 406-407) and an unnamed *Babesia* sp. (de Waal, Potgieter, Combrink, and Mason, 1990) occur in southern Africa and South Africa, but are not noted as economically important parasites. *Babesia bigemina* and *Babesia bovis* are the cause of African and Asiatic bovine babesiosis, which are two of the most economically important tick borne diseases to South Africa (de Vos *et al.* 2004:406; du Preez and Malan, 2008:40; Spickett, 2013:28; du Preez and Malan, 2015).

Babesia bigemina is the larger of the two parasites, and is either identified as single or paired in the erythrocytes of the cattle, varying in sizes of up to 4 μm long by 1.5 μm wide. The single organism is round, pear-shaped, or occasionally irregular shaped; the angle between the merozoites of pairs are typically acute (Potgieter, 1977; Riek, 1964; Roberts and Janovy, 2005:167; de Vos *et al.*, 2004:407). The interested reader is referred to Riek (1964) and Potgieter (1977) for a review of the *Babesia bigemina* morphology and life cycle in the *Rhipicephalus microplus* and/or *Rhipicephalus decoloratus* tick. It is, however, important to note that the development of the parasite depends largely on environmental temperatures, and it was found that this process was the most rapid when a replete female vector is held at 28°C (Riek, 1964).

Babesia bovis is either identified as single or paired in the erythrocytes of the cattle, varying in sizes of up to 2.3 μm long by 1.5 μm wide. The single organisms are round, oval or irregular in shape; paired organisms may be described as club-shaped and the angle between them is generally, but not invariably, obtuse (Potgieter, 1977; Riek, 1966a, 1966b:19; de Vos *et al.*, 2004:407). Like *Babesia bigemina*, the optimal development of *Babesia bovis* occurs when the replete female vector is held at 28°C (Riek, 1966b:20). The interested reader is referred to Riek (1966a, 1966b) and Potgieter (1977) for a review of the *Babesia bovis* morphology and life cycle in the *Rhipicephalus microplus* tick.

2.3 The tick vectors

Rhipicephalus decoloratus, commonly known as the blue tick, is a one-host tick and the vector of *Babesia bigemina* (Potgieter, 1977; Spickett, 2013:57). Cattle are its main domestic hosts, where other domestic animals are less important, but heavy infestations may occur on horses. Ticks have been collected off antelope amongst other wild animals (Walker, 1991). Under ideal conditions, the entire life cycle of a tick may be completed in circa two months, which may result in four generations per year. Larvae feed and moult to the nymphal stage on the same host after seven days. On the same host, nymphs will feed and moult to adults within seven days. Mating takes place on the host and after seven days of feeding, the replete female tick will detach herself and lay 2 000 - 2 500 eggs. Under ideal conditions, eggs will hatch within three to six weeks; the larvae will then search for a host from the vegetation (Arthur and Londt, 1973; Spickett, 2013:58). *Rhipicephalus decoloratus* is found largely within South Africa. Grassland and Indian Ocean Coastal belt biomes (the region of KwaZulu-Natal), the eastern and north-eastern portions of the Savanna

biome, as well as the Fynbos biome of the Western Cape are highly suitable areas of habitat. *Rhipicephalus decoloratus* has the greater distribution of the two vectors (Spickett, 2013:58-59; de Vos, 1979). The ticks' distribution is excluded from areas which experience a minimum average rainfall of 380mm per annum and decreasing humidity (Theiler, 1949) and areas of more than 90 days frost spread over a period of 150 days per annum (Gothe, 1976). Larvae are present on the vegetation from spring onwards. High numbers occur from summer and autumn up to the early winter months (de Vos *et al.* 2004).

The second vector of both *Babesia bigemina* and *Babesia bovis* is *Rhipicephalus microplus*, commonly known as the Asiatic blue tick. The one-host tick is said to have been accidentally introduced from southern Asia to South Africa through the transport of cattle via Madagascar in the late 1800's (Henning, 1949; Jongejan and Uilenberg, 2004; Potgieter, 1977; Spickett, 2013:60). The host range for this tick resembles that of *Rhipicephalus decoloratus*. It has occasionally been collected off other domestic, as well as wild animals, but cattle are its primary host (Walker, 1991). The life cycle of *Rhipicephalus microplus* is similar to that of *Rhipicephalus decoloratus*, but can lay up to 500 more eggs which may hatch sooner. The feeding phase is completed faster, therefore allowing it to detach itself from the host earlier to lay (Hitchcock, 1955; Spickett, 2013:61). *Rhipicephalus microplus* prefers warmer and more humid climates than that of *Rhipicephalus decoloratus*. It can maintain itself in areas with a maximum of 60 days frost spread over 150 days per annum, and the larvae can only tolerate temperatures of 0°C for 72 hours (Gothe, 1976). Optimal conditions for egg laying and larval hatching occur at temperatures of 15°C to 20°C and a relative humidity of 80% is necessary for egg survival (Sutherst and Maywald, 1985). Optimal survival conditions for the larvae is at 20°C and a relative humidity of 84% to 97% (Davey, Cooksey, and Despina, 1991). Certain areas limit its occurrence where there is less than an annual average rainfall of 500mm (de Vos, 1979). The species occurs in the Grassland and Savanna biomes with a high habitat suitability in the southern region of KwaZulu-Natal, north-eastern region of the Eastern Cape and north-eastern region of Limpopo (Spickett, 2013:61-62). Ticks are found in abundance on cattle from mid- to late-summer (de Vos *et al.*, 2004). In areas of southern Africa with higher rainfall, *Rhipicephalus microplus* has displaced *Rhipicephalus decoloratus* (Estrada-Peña, 2003). Further accounts of the indigenous *Rhipicephalus decoloratus* displacement by the exotic *Rhipicephalus microplus* have been reviewed (Horak, Nyangiwe, de Matos and Neves, 2009; Nyangiwe, Harrison and Horak, 2013; Tønnesen, Penzhorn, Bryson, Stoltz and Masibigiri, 2004). According to Spickett (2013:61) the displacement of *Rhipicephalus decoloratus* by *Rhipicephalus microplus* may be a result of males of the latter species copulating with females of the former, resulting in sterile eggs. With the displacement of *Rhipicephalus decoloratus* by *Rhipicephalus microplus*, the cattle industry is at greater risk due to its ability to complete a faster life cycle and that it can be the vector of both *Babesia* parasites but only the more virulent of the two.

2.4 Parasite transmission by the tick vectors

Rhipicephalus decoloratus and *Rhipicephalus microplus* both transmit *Babesia bigemina* to cattle. During the final stage of feeding on a host of the parasite, the female ticks are infected. The infection is passed transovarially via the eggs to the next generation; larvae are infected but not infective. The transmission of *Babesia bigemina* occurs only through the nymphal and adult stages of the ticks. Male ticks are successful transmitters of the parasite too. *Babesia bigemina* can be retained by a vector for at least one generation in the absence of the reinfection of a susceptible

host (Callow and Hoyte, 1961; Dalglish and Stewart, 1983; Gray and Potgieter, 1981; Potgieter, 1977; Suarez and Noh, 2011).

In South Africa, *Babesia bovis* can only be transmitted by *Rhipicephalus microplus*. During the final 24 hours of feeding on a host of the parasite, the female ticks are infected. The infection is passed transovarially via the eggs to the next generation. Only the larvae transmit the parasite whilst feeding two to three days after attachment and through this process rid themselves of the parasite. Neither the nymph nor the adult can transmit infection to the cattle (Dalglish and Stewart, 1983; Potgieter, 1977; Riek, 1966a; Suarez and Noh, 2011). The parasite has to complete its life cycle within the bovine host before it can be transmitted to the next generation of ticks (Mahoney and Mirre, 1979).

2.5 Resistance of cattle breeds to the tick vectors

Resistance to ticks is expressed by an increased mortality of developing young ticks and a reduced number of engorged adult female ticks (Riek, 1962; Roberts, 1968). It is widely accepted that *Bos indicus* cattle are less susceptible to ticks than their *Bos taurus* counterparts (Ibelli, Ribeiro, Giglioti, Regitano, Alencar, Chagas, Paço, Oliveira, Duarte, and Oliveira, 2012) and it has been reviewed that the former is more resistant to *Rhipicephalus decoloratus* (Mwangi, Stevenson, Ndungu, Stear, Reid, Gettinby, and Murray, 1998; Nyangiwe, Goni, Hervé-Claude, Ruddat, and Horak, 2011; Rechav and Kostrzewski, 1991; Spickett, de Klerk, Enslin, and Scholtz, 1989) and to *Rhipicephalus microplus* (Nyangiwe *et al.*, 2011; Seifert, 1971; Utech, Wharton, and Kerr, 1978; Wagland, 1975; Wharton, Utech, and Turner, 1970). *Bos indicus* and *Bos taurus* crossbreeds also show a greater resistance to *Rhipicephalus decoloratus* and *Rhipicephalus microplus* than that of pure *Bos taurus* breeds (Ibelli *et al.*, 2012; Miranpuri, 1989; Wambura, Gwakisa, Silayo, and Rugaimukamu, 1998). It is also known that naive *Bos indicus* animals have shown the ability to develop an acquired resistance to reoccurring tick infestations more successfully than that of *Bos taurus* cattle (Jonsson, Piper, and Constantinoiu, 2014; Miranpuri, 1989; Seifert, 1971; Spickett *et al.*, 1989; Wagland, 1975; Wambura *et al.*, 1998). However, Seifert (1971) shows that tick resistance may vary within animals of a specific breed too. Da Silva, Rangel, de Azevedo Baêta, and da Fonesca (2014) found that during peripartum, the animals of both breeds maintained their status of susceptibility to tick infestations.

2.6 Clinical signs

Clinical signs are usually observed two to three weeks after the cattle have been exposed to infected ticks and a fever reaching to temperatures of $>40^{\circ}\text{C}$ occurs first. After the development of a fever, signs such as the loss of appetite, weakness, listlessness, depression, increased respiratory rates and the unwillingness to move around can be noticed (Bock *et al.*, 2004; du Preez and Malan, 2008:41). Infections caused by both parasites are similar, but the course and outcome are often different (Callow (1984) as cited by de Vos *et al.* (2004)).

Babesiosis induced by *Babesia bigemina* is less virulent than that of a *Babesia bovis* infection. However, the development of the disease can occur quickly with sudden and severe anaemia,

jaundice and can be fatal if not attended to soon enough. Haemoglobinuria is consistently seen and is present as an early sign of infection (de Vos *et al.*, 2004:413).

Anaemia and jaundice are also present with the more harmful infections of *Babesia bovis* and are especially obvious in protracted cases, but haemoglobinurine is less consistent (de Vos *et al.*, 2004:413). Pregnant cattle which become infected may abort due to fever and bulls may experience reduced fertility lasting from anything between six to eight weeks (Singleton (1974); Callow (1984) as cited by Bock *et al.* (2004)). According to de Vos *et al.* (2004:413), hyperaesthesia, nystagmus, head pressing, circling, aggression, paralysis and convulsions are a variety of signs exhibiting central nervous system involvement. An infected animal demonstrating these neurological signs will have developed cerebral babesiosis; the course is short and the outcome often fatal.

2.7 Diagnosis techniques and treatment

A variety of diagnostic techniques exist, each with advantages and limitations. The techniques used are either concerned with the detection of the parasites or specific antibodies. The following techniques are briefly discussed on the accounts of Böse, Jorgensen, Dalglish and Friedhoff (1995), Bock *et al.* (2004), de Vos *et al.* (2004:416) and Mosqueda, Olvera-Ramírez, Aguilar-Tipacamú and Cantó (2012).

The detection of parasites can be achieved through microscopic detection, the more favoured and sustainable method for on-site diagnosis. Microscopic detection is inexpensive and reasonably portable. During acute disease thin blood films are used. It is difficult to differentiate between *Babesia bigemina* and *Babesia bovis* if parasitaemia levels are low and thicker blood films are needed. Thin blood films or organ smears from an animal that has recently become deceased can be used for post mortem diagnosis. A third microscopic technique is the Quantitative Buffy Coat system, but is not widely popular amongst veterinary labs due to the greater expenses it incurs. In vitro culture is a highly sensitive tool to identify carrier animals, but is limited as a diagnostic tool and requires costly tissue culture facilities. Isotests are costly and require experimental animals. Nucleotide detections involves DNA probes and the Polymerase Chain Reaction (PCR) techniques which detect parasite DNA in the blood, tissues or tick organs. The latter is preferred where high sensitivity is required.

Many immunological methods exist for the detection of *Babesia* antibodies, but few are used. The indirect fluorescent antibody test (IFAT) is the most widely used, the cost per test is low, and most reagents needed are easily accessible and can be produced on site. Usually 70 to 90 serum samples are examined. IFAT becomes time consuming and ineffective when large numbers of serum samples need to be processed. The more sensitive and efficient enzyme-linked immunosorbent assay (ELISA) test is therefore used. The immunochromatographic test (ICT) is a third method which is known to be a convenient and quick diagnostic device due to its low cost, ability to be implemented in the field and need for little specialised equipment.

2.8 Cattle immunity

It is widely accepted that animals of the *Bos indicus* and *Bos indicus* cross *Bos taurus* breeds demonstrate a higher resistance to *Babesia bigemina* and *Babesia bovis* infections than the *Bos taurus* species (Jonsson, Bock, and Jorgensen, 2008). Older cattle acquire a durable immunity against a *Babesia bigemina* or *Babesia bovis* infection after a drug related or self-cured recovery (Callow, McGregor, Parker, and Dalgliesh, 1974a; Callow, McGregor, Parker, and Dalgliesh, 1974b). A variation of resistance to *Babesia bovis* may occur in a primary infection in *Bos taurus* cattle (Benavides and Sacco, 2007). Mahoney, Wright and Mirre (1973) found that immunity to both parasites will persist for four years after a naturally acquired infection. If cattle are challenged regularly, immunity will be retained for the rest of their lives (Tønnesen, 2002). However, according to de Vos *et al.* (2004:412), persistence of infection is not required to ensure immunity. Cattle that have naturally eliminated infections will acquire strong and long lasting immunity whereas cattle that have been treated with drugs will acquire levels of resistance more related to the degree and duration of the antigenic stimulation rather than the presence of the parasites. Cross-protection against *Babesia bovis* can occur in cattle after the recovery of a *Babesia bigemina*, but not vice-versa (Wright, Goodger, Leatch, Aylward, Rode-Bramanis, and Waltisbuhl, 1987).

It is thought that calves less than two months born of immune dams have an innate immunity due to the passive transfer of antibodies in the colostrums and that those born from non-immune cattle are susceptible to infection (de Vos *et al.*, 2004:412). However, it had earlier been shown that calves born of non-immune dams exhibited resistance to the parasites (Riek (1963) as cited by Bock *et al.* (2004)). Goff, Johnson, Parish, Barrington, Tuo, and Valdez (2001) had shown that innate immunity are due to other factors. Calves possess this strong innate resistance for a period between two to nine months of age (Goff *et al.*, 2001; Tønnesen, 2002; de Vos *et al.*, 2004:412). During this phase, calves are required to become infected by the parasites in order to retain an immunity for the duration of their life (Zintl, Gray, Skerrett, and Mulcahy, 2005).

2.9 Endemic stability

Perry (1996), as cited by Bock *et al.* (2004), defined endemic stability as the "state where the relationship between host, agent, vector and environment is such that clinical disease occurs rarely or not at all". Callow (1977), as cited by de Vos (1979), defines endemic stability with regard to bovine babesiosis as "the condition where there is frequent transmission of the parasites and infection of all animals occurs during the period that young animals are protected within the first six to nine months of age." An infection rate of near 100% in calves at the age of nine months or before would indicate that endemic stability has been reached (Mahoney and Ross, 1972). An inoculation rate of 0.005 in calves by the age of nine months is associated with endemic stability having been achieved. This rate translates to at least 75% of the calf population being infected. Maximum threat out of an outbreak is associated with inoculation rates between 0.0005 and 0.005 at the age of nine months; commonly referred to as the 'zone of risk'. Endemic instability occurs whenever more than 25% of cattle of nine months and older experience a primary *Babesia* infection (Mahoney and Ross, 1972; Smith, 1991).

Based on the positivity of serological tests disease history of particular regions, Norval,

Fivas, Lawrence, and Daillecourt (1983) defined five different epidemiological situations, namely:

1. Endemically stable situations (81 - 100% positive sera)
2. Situations approaching endemic stability (61 - 80% positive sera)
3. Endemically unstable situations (21 - 60% positive sera)
4. Minimal disease situations (1 - 20% positive sera)
5. Disease-free situations (0% positive sera).

A stable situation concerning one *Babesia* parasite does not imply that there exists an equal state for the other (de Vos, 1979). The disruption of endemic stability may occur due to various reasons. The environment may not favour an adequate number of ticks, vector control by acaricides result in the suppression of tick population numbers below a level consistent with exposure to calves, or replacing immune cattle with adult animals which have not seroconverted (Jonsson *et al.*, 2008).

2.10 Inoculation rate

The proportion of nymphs, or adult, and larvae ticks bearing the *Babesia bigemina* or *Babesia bovis* parasite determine the infection rate. The risk that a bovine host receives a *Babesia* infection is expressed as the inoculation rate, which is determined by the number of tick bites that an animal receives daily and the proportion of larvae that are infected. The inoculation rate is defined as the daily probability of an animal becoming infected with *Babesia bigemina* or *Babesia bovis*. It measures the occurrence of infection and this controls the size and age structure of the non-infected segment of the cattle population (Mahoney and Ross (1972) and Mahoney (1974) as cited by Smith (1983) and Tønnesen (2002)). However, the inoculation rate assumes that the daily probability of infection is constant over time (Mahoney (1969) as cited by Ramsay (1997a)).

2.11 Control strategies

The methods of controlling bovine babesiosis vary amongst farmers. Cattle of the *Bovine indicus* genotype demonstrate a higher resistance to the infection of either *Babesia* parasite. Thus, depending on the prevalence of disease in certain areas, farmers may have a genetic preference towards cows in the light of bovine babesiosis control (Jonsson *et al.*, 2008). Others may be more inclined towards the use of live blood vaccines. Calves under the age of nine months are injected with the attenuated live blood vaccine ensuring the non-specific immunity to develop (Florin-Christensen, Suarez, Rodriguez, Flores, and Schnittger, 2014). Both these approaches are concerned with the regulation of outbreaks through the control of parasites.

Vector control can be performed by the use of acaricide treatments or vaccinations. Smith *et al.* (2000) provides the definition of four acaricide treatment strategies:

1. Threshold dipping: the application of acaricide treatments based on the level of economic importance perceived by the producer
2. Planned dipping: the application of acaricide treatments coinciding with management practices (pasture rotation)
3. Interval dipping: the application of acaricide treatments throughout the tick season, usually at regular monthly intervals. The monthly interval is based on the duration of the parasitic stage of the vector and the duration of the residual effect of the acaricide (usually no more than one week), and
4. Strategic dipping: the application of acaricide treatments timed mainly to achieve intensive control of overwintering tick generation, (including the Spring rise of larvae). A procedure performed in order to reduce the need for periodic dippings throughout the year.

2.12 Conclusion

Clinical infections after the occurrence of a primary infection from either *Babesia* parasite will result in production losses. Production losses in the form of weight loss may follow after the clinical signs such as loss of appetite, depression and unwillingness to move are observed. Abortions, death and reduced fertility are more severe production losses. Furthermore, treatment and diagnostic methods are also costly. Effective control of bovine babesiosis is complicated to implement due to the complex nature and factors associated with the parasites which cause the disease. The presence of bovine babesiosis is intermittently related to the distribution of the tick vectors and their sensitivity to climatic conditions, further depending on the proportion of ticks harbouring a *Babesia* infection and the number of cattle that recover from a primary infection. Various cattle breeds show different levels of resistance to tick infestations which may result in different management strategies from farm to farm. Amongst these cattle breeds, different levels of susceptibility to a primary *Babesia* infection are further considerations to account for. Intervention methods include vector control by means of acaricide use or inducing the state of endemic stability by means of attenuated live blood vaccines. The reviewed literature in this chapter will assist in the development of a model, discussed in Chapter 4, to explore the financial implications of developing endemic stability as a control strategy for bovine babesiosis through means of adopting less aggressive dipping programmes.

Chapter 3

Literature review: animal health

3.1 Introduction

Bovine babesiosis is regarded as one of the world's most economically important tick-borne diseases of cattle (Figuerola *et al.*, 2010:1822). Many peer reviewed journal articles concerning the study of parasitology, entomology, veterinary sciences and other related disciplines regularly note that bovine babesiosis is an economically important disease (Biggs, Carrington, and Naidoo, 2014; Gohil, Herrmann, Günther, and Cooke, 2013; Saleh, 2009). According to Mukhebi (1996) the economic importance of a disease can be shown by the amount of production losses the disease causes and the amount of prevention and treatment costs incurred by livestock producers and the government. Rushton (2009:195) identifies three levels at which the disease may have an impact; the individual livestock holder, a particular region and a national level.

Although bovine babesiosis is regarded as one of the globe's most economically important tick-borne diseases, there are few economic studies that have been conducted concerning its actual impact on any one of the three levels of the cattle industry. Reasons for the lack of economic studies available are largely attributed to the scarcity and the difficulties in the collection of relevant data concerning the direct and indirect costs of the disease (Rushton, 2009:197). The data needed for economic analyses are not always being provided for by the efforts of veterinary research (Tisdell, Harrison, and Ramsay, 1999). Merely quantifying the costs incurred as a result of the disease only confirms that a problem exists, one which obviously needs no confirmation.

This chapter reviews available literature concerning the economic impact of bovine babesiosis at the national level of various countries and concludes with those recorded for South Africa. An extensive literature search was conducted which yielded little information. All the studies found and reviewed have been published in the last 35 years. The discipline of animal health economics (AHE) is explored to identify frameworks used to assess the impact of livestock diseases, the effects it has on efficient production concluding with methods to optimally control disease. The discipline of AHE is further explored to establish the production effects of disease to consider when conducting an economic or financial assessment of livestock diseases and possible interventions. Published literature pertaining to the production effects of bovine babesiosis are also discussed. The treatment and prevention effects of bovine babesiosis on production are also reviewed. The chapter is

concluded with a review of the economic and financial models which have been used in the analysis of tick-borne-diseases and their respective control strategies.

3.2 The international and national impact of bovine babesiosis

Parasitic diseases have different impacts on livestock in the developed world and developing world. According to Perry and Randolph (1999), in the developed world the greatest impact of parasitic diseases are found in the form of control costs. In the developing world, the greatest impact is the component of production losses.

In Nigeria, Akinboade and Akinboade (1985) estimated that the average annual cost of bovine babesiosis equated to US \$540 million, which was only attributed to the loss in weight that a clinical infection caused. McLeod and Kristjanson (1999) developed a spreadsheet model which assessed the overall impact of ticks and tick-borne diseases in various countries. Unfortunately, the economic impact of babesiosis is not shown independently as it is combined with anaplasmosis. However, it is still one of the few existing indications estimating the detriment caused to the identified economies as a result of bovine babesiosis; their findings are summarised in Table 3.1. Kivaria (2006) estimated the annual direct costs associated with bovine babesiosis for Tanzanian agro-pastoral and pastoral cattle production systems to the value of US \$44.7 million. The difference in results when compared with those of McLeod and Kristjanson (1999) may be explained by Dijkhuizen, Huirne, and Jalvingh (1995) where difficulties arise when assessing the economic impacts of a disease due to the complexities associated with data collection and reliability. The estimation of direct and indirect costs is also included, thus largely influencing the accuracy of the results. The studies differ in the manner that acaricide costs were apportioned and that McLeod and Kristjanson (1999) considered the impacts of bovine babesiosis and anaplasmosis collectively. Meat and Livestock Australia estimated the annual cost of bovine babesiosis to be US \$21.6 million in 2006 (Carter and Rolls, 2014). In Southern Brazil, a 2005 survey showed that farmers lose an average of six animals per property per year due to bovine babesiosis (Benavides and Sacco, 2007). In Australia, Argentina and Mexico babesiosis contributes to the loss of US \$5 per animal due to tick-borne diseases (Figueroa *et al.*, 2010:1822). New Caledonia executed a violent campaign in order to eradicate the disease by slaughtering thousands of cattle at a cost of AU \$1 725 000 in 1992; the island was declared free from infection in 1994. In 2008, the island experienced an outbreak and another eradication campaign had been established, unfortunately no economic information is provided (Barré, Happold, Delathière, Desoutter, Sallery, de Vos, Marchal, Perrot, Grailles, and Mortelecque, 2011).

Information concerning the economical impact of the disease in South Africa is very limited. In 1971 to 1972 it was estimated that clinical infections caused the deaths of 8 000 cattle in Natal alone (de Vos, 1979). In 1980 it was estimated that losses caused by *Babesia bigemina*, *Babesia bovis* and *Anaplasma marginale* infections cost South Africa between R70 and R200 million per annum (Bigalke (1980) as cited by Regassa *et al.* (2003)). McLeod and Kristanjanson (1999) estimated the combined control costs and production losses of babesiosis and anaplasmosis at US \$22 million. More recent indications of the economic impact of bovine babesiosis is provided for by the average annual expenditure of R5.1 million on babesicides (Spickett, 2013:28).

Table 3.1: Annual costs of babesiosis and anaplasmosis.

Country	Estimated annual cost of babesiosis and anaplasmosis (\$US million; 1999 prices)
India	57.2
China	19.4
Australia	15.9
Kenya	6.9
Zimbabwe	6.2
Indonesia	3.1
Tanzania	2.8
Nepal	0.6

Source: Mcleod and Kristjanson (1999).

3.3 Defining the economic and financial impact of diseases in live-stock systems

When addressing the impact or cost of disease, it is imperative to correctly specify whether the analysis conducted is financial or economical. The former analysis involves costs and revenues, often involving cash transactions, which a livestock producer will appraise when calculating profits, considering current market prices and price distortions. The latter analysis is more comprehensive and considers non-cash costs and returns bearing hidden costs such as revenue forgone. These costs may also have an effect on society and the environment. Overall, it is understood that livestock diseases will have an economic impact as McInerney, Howe, and Schepers (1992) and McInerney (1996) explain. A reduced level of output not only financially affects the producer, but also the consumer. Other diseases have an economic impact due to their zoonotic characteristics, such as brucellosis (Addis, 2015). Therefore, a distinct clarification between a financial and an economical cost must be made.

Dijkhuizen and Morris (1997) and Rushton (2009) provide a framework which categorises the impacts of disease into direct and indirect losses. Direct losses comprise of all visible and invisible losses due to the presence of the disease. This results in the reduced production or mortality of the clinically infected animal. Components of indirect losses are additional costs including prevention and treatment, and revenue foregone such as denied access to higher value markets and the use of suboptimal technology (Rushton, 2009:195). There seems to be confusion within this framework among authors whom categorise the cost components of disease into direct and indirect impacts. Saatkamp, Mourits, and Howe (2014) reviewed articles of highly contagious livestock diseases where the authors analysed the same disease, but their categorization of cost components differed, therefore so did the end results of their impact analyses.

Prior to the frameworks of Dijkhuizen and Morris (1997) and Rushton (2009), McInerney *et al.* (1992) and McInerney (1996) had developed a simpler and more in-depth framework to economically analyse livestock disease by means of the expenditure-loss frontier, discussed later in this section. The authors discuss the concepts of loss and economic cost, the nature of control

expenditures and the measurement of disease costs. The confusion between the terms ‘loss’ and ‘cost’ are clarified. A loss (L) implies a benefit that is no longer (the death of an animal) or a potential benefit that is not realised (decrease of production as a result of an animal becoming clinically infected). In both instances there is a reduction in output. It is also evident that disease will have a financial or economical effect because of extra inputs in the production process. These resources are termed as expenditures (E). Expenditure represent the resources that have been allocated to unplanned or non-preferred uses such as a vet call-out or taking measures to counteract the threats of a sudden occurrence of disease. Expenditures are the sum of two sub-components. Firstly, they are treatment expenditures that are incurred after the impact of disease has prevailed. Secondly, they are prevention expenditures which occur before the impact of disease in an attempt to avoid the ill effects. Treatment is an ex-post response to disease whereas prevention is an ex-ante response to the possibilities of disease occurring. Either the livestock producer may choose to favour the use of more resources in the prevention or treatment to control a disease; prevention and treatment are seen as substitutes. Prevention and treatment are also used simultaneously as part of a disease-control policy. Therefore, expenditures on disease control represent the total value of resources used to either reduce, or impede, potential losses due to output reductions. A close similarity exists of the ill effects of disease given by McInerney *et al.* (1992) and McInerney (1996) and those by Dijkhuizen and Morris (1997) and Rushton (2009), but the arguments and discussions delivered by the former authors are clearer and more descriptive.

McInerney *et al.* (1992) and McInerney (1996) identified that the negative effects of disease from an economic perspective undoubtedly appears in either component of a loss or an expenditure. Therefore, an economic cost (C) will arise as a result of the sum of the two components at the presence of a disease. It is identified by the simple identity $C = L + E$ where the objective is to minimise C . The authors recognise that the true measure of the economic costs of disease must account for the true economic values. It should also consider the social and environmental impacts which may have no associated values in the form of market prices but may be represented in the form of hidden costs.

Bennett, Christiansen, and Clifton-Hadley (1999) and Bennett (2003) expand on this framework. The authors specifically define the ‘direct disease costs’ (C_D) in order to make it clear that the indirect costs (social and environmental impacts, animal welfare, international trade etc.) of disease are not included in the analysis. The components of expenditures as defined by McInerney *et al.* (1992) and McInerney (1996) is separated by Bennett (2003) for the purpose that ‘veterinary inputs’ are seen by both state veterinary service and policy makers as inputs that may be subject to government intervention in the form of national policies on disease control. The direct disease cost is identified by the identity $C_D = (L + R) + T + P$ where

- L is defined as the loss in value of expected output as a result of disease presence
- R is the increase in expenditures on non-veterinary resources due to a disease (feed, labour etc.)
- T is the cost of treatment inputs
- P is the cost of disease prevention measures.

Bennett (2003) further identified that disease in livestock had seven main economic impacts, namely:

1. Reduction in the level of marketable outputs
2. Reduction in perceived or actual output quality
3. Waste or higher level of use of inputs
4. Resource costs associated with disease prevention and control
5. Human health costs associated with disease or disease control
6. Negative animal welfare associated with disease
7. International trade restrictions due to disease and its control.

Since Bennett's (2003) original attempt at defining the direct cost of disease it has been widely adopted for impact assessments for various production illnesses such as paratuberculosis (Bennett, McClement, and McFarlane, 2010), lumpy skin disease (Gari, Bonnet, Roger, and Waret-Szkuta, 2011), Johne's disease (Bennett, McClement, and McFarlane, 2012) in cattle and bluetongue in sheep production systems (Fofana, Toma, Moran, Gunn, Szmaragd, and Stott, 2015). In some cases Bennett's (2003) framework has gone beyond livestock systems and has been applied in the impact assessment of salmonid diseases in aquaculture (Fofana and Baulcomb, 2012). Singh, Dhand, and Gill (2015) calculated the impact of brucellosis only on the losses of cattle, sheep, pig, goat and buffalo production systems. This study was not concerned with the financial impact the disease caused the farmer, but rather the particular industries as a result of mortality and morbidity. The scope of Singh, Dhand, and Gill (2015) was not to include the prevention, treatment nor the non-veterinary expenditures, therefore their results do not show the true direct costs of brucellosis. Few studies have adopted the framework of Bennett *et al.* (1999) and Bennett (2003) in assessing the impact of tick-borne diseases. Inci, Ica, Yildirim, Vatansever, Cakmak, Albaskan, Cam, Atasever, Sariozkan, and Duzlu (2007) and Sitawa, Mbogoh, and Gathuma (2016) both used the framework when assessing the costs and benefits of vaccine control strategies for the control of tropical theileriosis and theileriosis, commonly known as East Coast fever. Kivaria (2006) and Kivaria, Ruheta, Mkonyi, and Malamsha (2007) were the only two found studies that use the framework which include an impact analysis of bovine babesiosis. However, both studies are not bovine babesiosis specific and include east coast fever and anaplasmosis as well.

The frameworks of McInerney *et al.* (1992), McInerney (1996), Bennett *et al.* (1999) and Bennett (2003) largely focus on estimating the economic impact of disease at the national level. Hogeveen and van der Voort (2017) expand these frameworks by tailoring it to fit the needs of the farmer. As did the former authors, Hogeveen and van der Voort (2017) primarily consider the production process of a farm being made up of a technical relationship between resources used and products produced, of which the impact of a production disease should be based on. The impact of disease on production is illustrated by the production function in Figure 3.1 where a healthy farm is compared with a diseased farm. Given a fixed amount of resources at R_1 , the healthy farm will produce an output of Q_{H1} at point A whereas the diseased farm will produce an output of Q_{D1} at point B. Therefore, disease reduces the amount of output produced by $Q_{H1} - Q_{D1}$. Similarly this is illustrated by the healthy farm producing an output at point C and the diseased farm producing an output at point D. The difference in output produced is therefore $Q_{H2} - Q_{D2}$. However, for the diseased farm to produce an equal output of Q_{H2} as the healthy farm at point C, an increase in variable resources is required. Increasing the resources needed by $R'_2 - R_2$ the diseased farm is able to increase the output produced from point D to point E by shifting along the production curve.

With the challenge of disease and the effects on production it brings, it has been expressed that two alternative production choices can be made as illustrated by points C, D and E. Either a farm produces less output with unchanged variable resource inputs and the value of damage is realised by multiplying the change in output by the output price. Alternatively, the farm produces an equal output with an increased level of variable resource inputs and the value of damage is realised by multiplying the change of resource inputs with their respective price.

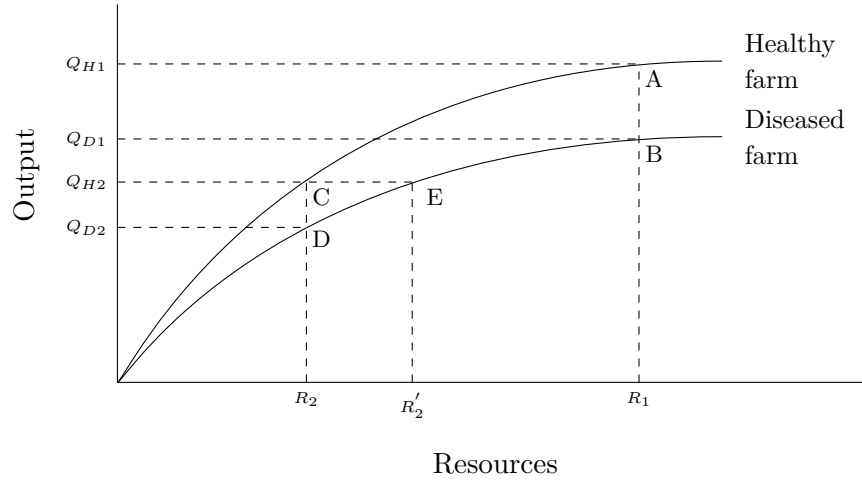


Figure 3.1: The production function illustrating the effect of disease on a farm. Source: Hogeveen and van der Voort (2017).

Assessing the impact of disease on production is difficult since the optimal level of production depends on the prices of inputs and outputs. Furthermore, production varies from farm to farm which hinders the ability to correctly estimate the on-farm effects of disease in a theoretical manner. The framework of Hogeveen and van der Voort (2017) accounts for this difficulty by offering a more pragmatic approach to assess the on-farm impacts of disease. By building on the frameworks described by McInerney *et al.* (1992), McInerney (1996), Bennett *et al.* (1999) and Bennett (2003), Hogeveen and van der Voort (2017) provide an approach for an impact assessment of disease at the producer level.

A distinction between the failure costs (C_f) and preventive costs (C_{pr}) of disease is specified where the sum of these two cost components is defined as the partial costs of disease (C_{pa}). Failure costs are incurred due to disease occurrence, consisting of production losses (L), treatment expenditure (T) and the associated additional resource costs (R_f) where $C_f = L + (T + R_f)$. The additional labour needed to treat and care for the infected animal is considered as an additional resource. A substitution relationship between expenditures within these failure costs exist; additional resources for treatment, and production losses. A greater production loss will lead to lower resource and treatment expenditures and vice versa. Preventive costs (C_{pr}) include preventive expenditure (P) and additional resources (R_{pr}) used associated with the prevention of disease occurrence where $C_{pr} = P + R_{pr}$.

A trade-off between the failure and preventative costs therefore exists. The desired result of $C_f + C_{pr}$ is to attain the lowest possible C_{pa} . The partial cost of disease is identified as is, in order to determine the optimal level of failure and preventive costs at the producer level. The

expenditure-loss frontier in Figure 3.2 illustrates the relationship between the failure and preventive costs and the optimal combination of both to achieve the lowest possible C_{pa} .

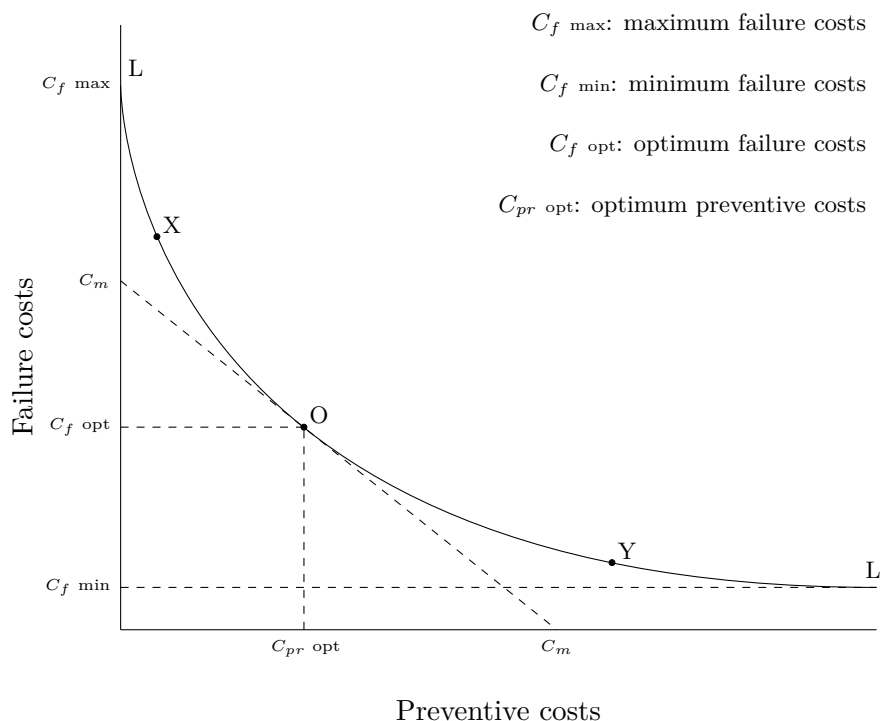


Figure 3.2: The expenditure-loss frontier illustrating the trade-off between failure and preventive costs. Source: Hogeveen and van der Voort (2017).

The expenditure-loss frontier introduced by McInerney *et al.* (1992) and McInerney (1996) emphasising the equi-marginal principle has long been the theoretical foundation of AHE studies (Houe, 2003; Hogeveen, Huijps, and Lam, 2011) as well as supporting the frameworks previously discussed. The combination of failure and preventive cost is defined by the efficiency frontier line LL'. Maximum failure costs are incurred where LL' intercepts the y-axis at $C_{f \text{ max}}$ due to no disease prevention. With progressive increases in preventive expenditure, the failure costs decrease as illustrated by point X. Point Y indicates that a large increase in preventive costs results in a greater decrease of failure costs. However, prevention costs increase at a diminishing rate because of diminishing marginal returns and it becomes more difficult to secure further failure costs. The optimal cost of disease is realised where an additional monetary unit spent on prevention equals additional monetary unit saved on failure costs. This is illustrated by the conventional iso-cost line C_m as it is shifted rightwards and intercepts LL' at point O.

The development of frameworks within the AHE discipline has been paid a great amount of attention to the economic impact of diseases. This has been done in order for better estimates pertaining to the optimal cost of disease to be achieved at the national, regional and individual livestock holder level. The economic impacts include treatment, prevention and additional resource expenditure in the form of cash outflows. Furthermore, the economic impact considers the loss in production such as weight loss or the death of an animal which can be both valued at the market price (Rushton, 2009:196). However, such production losses do not take the form of a cash outflow,

and therefore should not be considered in the financial impact of disease. Production losses are rather reflected in the form of a reduction in cash inflows due to lighter or fewer animals reaching the market as a result of weight loss or death, respectively. The financial impact of disease and disease control strategies should therefore only consider the increase or decrease of cash flows as a result of the production effects encountered (Rushton, 2009:76).

3.4 The production effects of disease with reference to bovine babesiosis

The effects of disease on production are of utmost importance when designing an economic or financial study as they provide an indication of the losses that can be avoided when compared to a healthy or healthier production system. Therefore, physical measurements of the production process must be satisfactory. It should not be forgotten that an attempt at avoiding production losses will incur costs. It is, therefore, only beneficial to avoid the production losses if the costs incurred to achieve this objective are less.

Many complexities are involved in determining the effects of bovine babesiosis in cattle. This is due to the amount of variables involved such as age, primary infection, endemic stability (Mahoney and Ross, 1972), susceptibility of breed to the parasite (Jonsson *et al.*, 2008) and vectors (Ibelli *et al.*, 2012), virulence of the parasite (de Vos *et al.*, 2004), the distribution of tick vectors and the prevalence of the parasite (Spickett, 2013). Morris and Meek (1980) discuss the effects that acute and chronic diseases have on production. Since bovine babesiosis is considered as an acute disease (Bock *et al.*, 2004) the latter is ignored. Morris (1997) provides an expanded framework of Morris and Meek (1980) which extensively reviews how mechanisms are affected by disease such as feed digestibility; feed ingestion; and a variety of psychological processes, which further manifest into productivity effects. The following impacts of parasitic diseases are discussed on the account of Morris (1997), Tisdell *et al.* (1999) and Rushton (2009).

Production losses as a result of death will have an effect on the structure of the herd. The effect of deaths are often overemphasized as a result of its simplicity to record. According to Morris (1997) this production loss should be recorded as the difference in potential value when ready for sale and the animals' value at the point of death less the costs incurred in obtaining its market value. It is true that death will result in fewer animals available for sale which will in turn have an effect on future revenues. According to Rushton (2009) the definition of direct costs are those that happen as a direct result of disease, therefore the above statement according to Morris (1997) should be considered as part of the indirect costs which are to follow later in discussion. Therefore, death as a direct cost should be recorded as the value of an animal at the point of decease.

A clinical infection of bovine babesiosis does have the ability to cause the death of an animal, but it is no simple task to determine the rate at which death may occur due to the above mentioned variables. According to de Vos (1978) mortality rates of 10% of susceptible cattle in South Africa when introduced into endemic bovine babesiosis regions where *Rhiphicephalus microplus* numbers were high and according to Bock, de Vos, Kingston, and McLellan (1997) a primary infection of *Babesia bovis* in mature *Bos taurus* animals can result in mortality rates of over 70%. The values that Kivaria (2006) prescribes to the risk of case fatality differ largely. However, they are prescribed on the basis of the total cattle population at risk of bovine babesiosis, and of that

number the proportion that may die.

Weight loss as a result of infection is considered a production loss which is reliant on various factors. The most important factors are the amount of weight lost, the composition of the weight lost and the rate at which it is recovered known as compensatory growth. Breed, age, live-weight and maturity, stage of growth condition, severity and duration of infection, type of feed, and level of nutrients in the feed are further factors to consider when determining the compensatory growth (Tisdell *et al.*, 1999). A bovine babesiosis infection will cause weight loss in an animal, but little work has been conducted to measure this effect and the variation of it. Solari, Nari, and Cardozo (1992) found statistically significant differences of greater live weight gains in non-infected *Bos taurus* heifers in comparison with animals acutely infected with *Babesia bovis* when fed on natural pastures. In the same study, the authors found further statistical significance in greater live weight gains that immunised animals achieved after facing a parasite challenge in comparison with the control animals. Their results corroborated with those of Montenegro-James, Ristic, Benitez, Leon, and Lopez (1985) whom also found significant differences in the weight gains of eighteen month old immunized cross-bred Holstein (*Bos taurus*) cattle compared with the non-immunized control group when both were introduced to a *Babesia bovis* challenge. Kivaria (2006) estimated that an average of 4 600t of weight loss occurs annually as a result of the disease in Tanzania; bovine babesiosis and cattle breeds are referred to in general in this study. Guglielmone, Aguirre, Spiith, Gaido, and Mangold (1992) assumed that a *Bos taurus* animal would lose 10% of its body weight when suffering a clinical *Babesia bigemina* or *Babesia bovis* infection. No further information was found concerning the production effects that *Babesia bigemina* may have on the productivity of an animal nor of *Babesia bovis* affecting *Bos indicus* cattle.

The quantity and quality of milk produced can be affected by disease. The effects of quantity produced can vary from either a mild reduction or complete halt, depending on the severity of the disease and at the stage of lactation that infection occurs. In beef production systems, the effect of disease on lactation is concerned with the growth and survival of the calves. The literature that exists regarding the effect of bovine babesiosis on milk production is extremely sparse. De la Fuente *et al.* (1998) estimated that milk production would increase largely if *Babesia bovis* and *Babesia bigemina* infections were controlled effectively by the control of *Rhipicephalus microplus* in comparison with a pilot study assessing the losses caused by infection. The study used a large sample, but variables concerning the cattle breeds and age nor the *Babesia* parasites are mentioned. Laha, Das, Goswami, and Singh (2012) recorded an average daily decrease in milk production as a result of a *Babesia bigemina* infection in a four year old cross-bred cow.

Disease can have several effects on the reproduction mechanisms of males and females; the former is discussed first. The factors of reproductive efficiency that can be affected by disease are considered on the account of Tisdell *et al.* (1999) and where it is possible the literature examining the effects of bovine babesiosis on reproduction is reviewed.

The effects of disease on male reproduction is restricted and relate to the ability of the male to to seek, mate and fertilise receptive females. The following effects are summarised:

- Temporary infertility due to effects on spermatogenesis and sperm survival due to increased body temperatures associated with the disease. This may occur when a clinical bovine babesiosis infection persists (Bock *et al.*, 2004)
- Temporary or permanent infertility as a result of the direct effects of a disease on spermatogenesis

genesis

- Reduced mobility, therefore affected animals are not able to seek and mate with receptive females
- Reduced libido.

The effects of disease on the female reproduction process will vary according to the time that the disease occurs in relation to the reproductive cycle of the individual animal. The system of breeding management, either controlled, seasonal or continuous, will influence the proportion of females at each stage of their reproductive cycle during different times of the year, and therefore disease will effect the reproductive performance of a herd. No literature concerning the effect that bovine babesiosis has on female reproductive performance was found. However, the effects of disease on female reproductive efficiency is summarised below:

- Silent oestrus periods
- Prevention of fertilisation
- Early embryonic loss
- Loss in mid gestation
- Abortion in the last trimester of pregnancy
- Birth of dead, weak, or deformed calves which die postpartum
- Delays in heifers breeding due to decreased body weights and being below optimal condition.

Other direct costs include production losses due to poor product quality. Ticks and tick-borne diseases can cause the downgrading of live animals at sales, and of meat, hides and offal. In developing countries where the use of technology is limited, animals are used as a source of traction in the preparation of fields for crop production. Disease which affects the mobility and strength of an animal will have an effect on crop production. Dung in developing countries is a vital resource as it can be used as cooking fuel and/or fertilizer. A disease which causes high mortality rates will alter the production of dung for fuel and fertilizer. The effect of disease has on both the capacity for an animal to work and dung production indirectly affects human welfare in developing countries (Morris, 1997).

3.5 The treatment and prevention effects on production with reference to bovine babesiosis

No literature could be found concerning non-veterinary expenditure of bovine babesiosis. Although de Vos *et al.* (2004) discuss the supportive therapy needed if treatment occurs too late which will form part of the failure costs. The continuous use of drugs to treat cases of bovine babesiosis may become costly if used as a permanent management strategy, despite its effectiveness. In the past, when the management of bovine babesiosis focussed on treatment, many drugs proved

to have a positive effect against the pathogenesis of *Babesia bigemina* and *Babesia bovis* (de Vos *et al.*, 2004). Mosqueda *et al.* (2012), in their review of current advances in detection and treatment of babesiosis, elaborate on the drugs used and those no longer in use. The most commonly used chemical compounds for the treatment of bovine babesiosis are diminazene diaceturate, imidocarb dipropionate and amicarbalide (Vial and Gorenflot, 2006). Other drugs used to treat bovine babesiosis are available (de Vos *et al.*, 2004:419; Figueroa *et al.*, 2010; CEVA, 2017).

In the light that chemoprophylaxis may be continuous, generally short-lived, and therefore has the potential to become costly; there exists prevention. However, two of the most commonly used chemoprophylactic treatments for bovine babesiosis, diminazene and imidocarb, are useful as short-term prevention strategies against bovine babesiosis. Diminazene will prevent infection of *Babesia bigemina* for two weeks and *Babesia bovis* for one week. Imidocarb will protect cattle from a *Babesia bigemina* infection for at least eight weeks and a *Babesia bovis* for at least four weeks (Bock *et al.*, 2004).

The cognisance that an animal can adapt and develop immunity after a primary infection to either *Babesia bigemina* or *Babesia bovis* caught the attention of veterinary scientists. In 1964 the development of attenuated live vaccines using infected blood began. Their intended use is to mimic the natural process of parasite transmission from tick vector to the host in order to develop an immunity (Gohil *et al.*, 2013). Three to four weeks after injection, the protective immunity will develop (de Waal and Combrink, 2006). The vaccines contain a low parasitaemia level and are therefore less virulent. The recommended use of the vaccines should be applied to calves during their period of non-specific immunity. However, if adult animals require the injection, close monitoring is required as cases of acute bovine babesiosis may develop and babesiacide treatment may often be needed (Florin-Christensen *et al.*, 2014). A single inoculation provided a long-lasting immunity against either of the targeted parasites and no loss of immunity was found over time. In Australia, no conclusive evidence existed that the vaccines did not serve their purpose. The same is corroborated in South Africa. However, failures in the use of *Babesia bovis* attenuated live vaccines were evident, but uncommon, as a result of host immune responsiveness, age, and immunogenicity of the vaccine strain (Bock and de Vos, 2001). In the past South Africa was supplied with bivalent chilled vaccines. For various benefits, vaccines are now being produced as deep frozen vaccines and containing only a single parasite strain. Dosage requirements are 1ml per animal irrespective of bodyweight (de Waal and Combrink, 2006).

The control of the tick vectors is a strategy used to prevent the transmission of the parasites to the animal. Acaricides are applied on to the animal by various methods such as plunge, spray-race or pour-on dipping. A method was developed to assess the efficiency of acaricide application by Wharton, Roulston, Utech, and Kerr (1970). Results show that the mode of acaricide application will have a significant effect on number of attached ticks (*Rhipicepalus microplus*) found on the animal. However, it is in the livestock producers own interest to use whichever mode they see best fit. The intensive uses of acaricides have the ability to destroy endemic stability, and lack thereof to induce it, is comprehensively reviewed in the literature (Regassa *et al.*, 2003; Rikhotso *et al.*, 2005; Tice, Bryson, Stewart, du Plessis and de Waal, 1998; de Vos and Potgieter, 1983). Beyond the destruction of endemic stability as a result of intensive control measures, the tick vectors can develop a phenomenon of acaricide resistance (Rodriguez-Vivas, Trees, Rosado-Aguilar, Villegas-Perez, and Hodgkinson, 2011). The combination of infective and acaricide-resistant ticks with a susceptible herd can result in a bovine babesiosis outbreak. Alternative and less aggressive methods of tick control methods exist with the availability of GavacTM and TickGARD vaccina-

tions (Suarez, Rubi, Pérez, Cordova, Salazar, Vielma, Barrios, Antonio, Segura, Carrillo, Cartaya, Palacios, Rubio, Escalona, Chacon, Basulto, Machado, Sordo, Bermudes, Vargas, Montero, Cruz, Puente, Rodriguez, Mantilla, Oliva, Smith, Castillo, Ramos, Ramirez, Abad, Morales, Gonzalez, Hernandez, Ceballo, Callard, Cardoso, Navarro, Luis, Pina, Cueto, Borroto, Pimentel, Carpio, and Pablo, 2016).

3.6 The economic and financial management of tick-borne diseases

The use of disease cost figures reviewed in Section 3.2 creates an awareness regarding the general magnitude of the losses associated with bovine babesiosis. In the past, results of similar cost quantifying studies have been used to justify research programmes and persuade policy-makers that a particular disease should be controlled. Morris and Meek (1980) describe this approach as ‘undesirable’ because it incorrectly infers that the amount of money is completely recoverable and would only be the case if perfect disease control could be achieved at zero cost. The true role of an agricultural economists is not to quantify the cost of disease. This task is no more than an ‘accounting exercise’ as McInernery (1996) defines it and usually ignores the consideration of what component of these losses can be realistically reduced. Therefore, little to no value is added in the decision-making process. Perry and Randolph (1999) describe that the true impact of disease should be assessed with regards to the results of the various control strategies implemented. However, it must be recognised that the estimation of costs associated with disease is the first step in conducting an economic or financial analysis of control strategies. Hence, the frameworks reviewed in Section 3.3. A natural progression follows once direct costs may be estimated and a financial analysis may be performed testing the strategies at hand.

Section 3.6 reviews the economic and financial models used when analysing various control strategies addressing tick-borne diseases. An extensive literature search was conducted in Google Scholar using search phrases such as; tick AND disease AND economic AND analysis; tick AND disease AND "cost benefit"; "bovine babesiosis" AND economic AND control, amongst many other options. Through the searches, it was realised that peer reviewed literature concerning economic and financial analyses of tick-borne disease control strategies are scarce, however, the following prevails.

Economic analyses of tick-borne disease control strategies are mostly concerned with theileriosis. With this disease, there is a general trend of assessing the economic viability of an immunisation control strategy strongly referred to as the infection and treatment method (Radley, 1981), as well as other strategies. The use of cost benefit models are the most commonly used tools in the decision-making process. Mukhebi, Perry, and Kruska (1992) analysed three post-immunisation scenarios in comparison with a current control strategy that did not include immunisation. The assumptions of the authors were that each scenario of immunisation would decrease the incidence of theileriosis and acaricide use, except for one. The scenarios applied to national cattle populations of the countries under study. Results showed according to the cost benefit analysis that all three post-immunisation control scenarios proved to be economically viable based on their assumptions. A sensitivity analysis was performed on the price on the vaccination in order to determine the break-even immunisation cost. Similarly, Kivaria *et al.* (2007) assessed the economic implications of six different control strategies of theileriosis. The study had its attention drawn towards dairy cattle of extensive, semi-extensive and zero grazing management systems. The current control strategy

involved the application of acaricides twice weekly and no infection and treatment method. The second possible option introduced the infection and treatment method and no reduction in acaricides. The third strategy involving the infection and treatment method decreased the acaricide use by 25% until the sixth strategy where a 100% decrease in acaricide use could be attained. The introduction of immunisation resulted in cost reductions ranging from 40% - 68% for the various strategies, accompanied by increases in net income from 4.0% - 58%. In the particular study of Kivaria *et al.* (2007), a cost benefit analysis justified the immunisation and treatment method against theileriosis where the control strategy that decreased acaricide use by 50% and 75% for extensive and zero grazing systems, respectively.

Gharbi, Touay, Khayeche, Laarif, Jedidi, Sassi, and Darghouth (2011) conducted a financial impact analysis of three different control strategies for theileriosis. They focused their attention on the general dairy population of endemic instability in Tunisia. The use of a cost benefit analysis was used to determine the predicted benefits of three different control strategies, namely; the application of acaricides; infection and treatment method; and the upgrading of barns. Under their epidemiological scenarios, results prove that the upgrading of barns produced the best cost-benefit ratio consistently higher than one. The upgrading of barns is beneficial because it is based on a single investment. However, it is closely related to an eradication based control strategy, therefore why it may be beneficial for endemically unstable states.

The uses of other economic analysis tools have been used when attempting at orchestrating the best-fit control options against theileriosis. D'Haese, Penne, and Elyn (1999) adopted the total economic cost methodology proposed by McInerney *et al.* (1992) and calculated the impact of different control strategies over thirty years. Results showed that there was no single best-fit option for the control the disease. A financially viable farm specific control strategy depended largely on the occurrence of theileriosis. However, in their herd projection model based on subclinical theileriosis case assumptions, it was found that immunisation was the best strategy followed by treatment.

A less common economically investigated tick-borne disease is heartwater. Mukhebi, Cham-boko, Callaghan, and Peter (1999) investigated the economic impact of this disease and the introduction of a new vaccine using a cost-benefit analysis. The model used in the analysis was discounted over a period of ten years. It considered communal and commercial systems, high and lowveld zones, and four different epidemiological states. The introduction of a new vaccine suggest that it may be slightly less financially viable than the current control strategy in the communal systems, but beneficial for the commercial systems. Furthermore, gross margins per animal increased in commercial systems but remained the same in the communal systems.

Studies addressing the financial or economic implications concerned with the control strategies of bovine babesiosis are not in abundance. However, diversity exists in the analyses of bovine babesiosis control strategies unlike the strong trend of immunisation encountered with theileriosis studies as well as the economic analysis tools used. De la Fuente *et al.* (1998) assessed the impact of a vector control strategy against *Rhipicephalus microplus* using the GavacTM vaccination. A cost-effectiveness study was performed which included over 260 000 cattle. The application of the vaccination against the tick vectors decreased the use of acaricides by 60%. Under the specific field experiments, the transmission of *Babesia* parasites decreased and the incidence of diseased and dead animals reduced. This further translated into a total savings of \$23.40 per animal per year. In a homogeneous manner concerning vector control strategies, it was shown that a once-a-month dipping approach was financially beneficial compared with a twice-a-week plan (Okello-Onen, Mukhebi,

Tukahirwa, Musisi, Bode, Heinonen, Perry, and Opuda-Asibo, 1998). Biological results showed that the intensive dipping strategy meant better results compared with less intensive and no tick control options. However, the gross margin analysis was greatest for the less intensive dipping strategy. The marginal rate of return for changing from no tick control to once-a-month dipping was 160%. This is in contrast with the marginal rate of return of -313% when moving from no tick control to twice-a-week dipping, indicating total financial inefficiency despite the biological benefits.

The use of attenuated live vaccines as a control strategy has been financially analysed. Guglielmone *et al.* (1992) conducted a study on Holstein Friesian dairy calf cohorts where they were vaccinated with attenuated *Babesia bigemina* and *Babesia bovis* vaccines. Values of the costs and losses avoided by the vaccination and the cost of the use of the vaccine were used in a cost-benefit analysis. The control strategies compared were those cohorts that were vaccinated and those that were not. No cases of bovine babesiosis occurred in the vaccinated cohorts and 26% of the non-immunised cohorts were clinically diagnosed. This led to the conclusion that the use of the attenuated live vaccines as a control strategy against bovine babesiosis had a cost-benefit ratio of 4:1. Although the results of Guglielmone *et al.* (1992) show that the use of attenuated live vaccines are financially beneficial in the control of *Babesia bigemina* and *Babesia bovis* infections, Carter and Rolls (2014) provide a far more descriptive cost benefit-analysis of a trivalent vaccine. The vaccine offers protection against bovine babesiosis and anaplasmosis. Their study examines three different cattle genotypes; *Bos indicus*, *Bos taurus* and *Bos indicus* cross *Bos taurus*, as well as at the various disease seroprevalence rates. Their descriptive impact assessment clearly identifies differences when compared with Guglielmone *et al.* (1992) and provides an in depth analysis of when best to use the vaccine according to cattle genotype and seroprevalence of disease. Specific cost-benefit ratios and net present values showed that the application of the vaccine on *Bos taurus* cattle were greatest, and greater benefits are realised when considering a *Babesia bovis* infection opposed to a *Babesia bigemina* infection. The use of the vaccine in *Bos indicus* cattle yielded cost-benefit ratios less than one and negative net present values across all seroprevalence rates for both parasite infections. Results for the protection against *Babesia bigemina* infections were less favourable than *Babesia bovis* in *Bos indicus*/*Bos taurus* crossbreeds. Table 3.2 summarises their results.

Partial budgeting has been used at a farm level for the analysis of various disease control strategies such as lumpy skin and foot and mouth diseases (Gari *et al.*, 2011; Young, Suon, Andrews, Henry and Windsor, 2013). In the realm of tick-borne diseases, the tool is closely related to theileriosis and the infection and treatment method control strategy. Mukhebi *et al.* (1992) introduced the use of a partial budget to analyse the incremental benefits and costs between the infection and treatment scenarios. The incremental benefits accrued from the extra income realised as a result of production losses avoided due to theileriosis case morbidity and mortality and cost saving from reduced acaricide usage. Incremental costs consisted of the vaccination costs and revenue forgone by the government from dipping fees and the sale of acaricides. Their cost-benefit ratio was then calculated according to the incremental benefits and costs. Partial budgeting showed that the infection and treatment method proved beneficial results for the control of tropical theileriosis. Veterinary intervention, mortality costs, slower weight gains and weight loss cost components could be satisfactorily avoided in an endemic state of Friesian-Holstein crossbred calves. A cost-benefit ratio ranging between 16.4 and 18.3 concludes the results (Gharbi, Sassi, Dorchies, and Darghouth, 2006). In smallholder production systems this strategy was closely analysed by Wesonga (2013). Net income would increase between 24% and 100% depending on the alternative control strategy

at hand. The cost-benefit ratio yielded financially profitable in grade, but not zebu cattle at a price of Ksh 544 (US \$25, 1990 values). For the strategy to be financially profitable for zebu cattle, the cost of immunisation per animal would have to fall in the range of Ksh 230 - 415. Alternatively, the farm-gate price of milk would have to increase by a minimum of 80%. Other studies prove beneficial results with the use of immunisation as a control strategy against theileriosis compared with intensive acaricide usage (Sitawa *et al.*, 2016; Tenesi, 2015; Wangila, 2016).

There are little studies known where the financial impact of a natural infection is considered as control strategy in comparison with others. Martins, Di Giulio, Lynen, Peters, and Rushton (2010) compared a natural infection combined with anti-theilerial treatment with improved detection and management strategy with the popular infection and treatment method. Their study was performed over a twelve month field trial. As in the aforementioned studies, the infection and treatment method proved greater benefits than the alternative assessed.

Table 3.2: Cost-benefit analysis of vaccination for bovine babesiosis.

Parasite infection	Genotype	Financial indicator	Seroprevalence				
			10%	30%	50%	70%	90%
<i>Babesia bigemina</i>	<i>Bos taurus</i>	BCR	2.4	3.8	3.1	1.7	0.4
		NPV	\$10 169	\$20 303	\$15 290	\$5 269	-\$4 345
	<i>Bos indicus</i>	BCR	0	0	0	0	0
		NPV	-\$7 274	-\$7 250	-\$7 270	-\$7 299	-\$7 321
<i>Babesia bovis</i>	<i>Bos taurus</i> / <i>Bos indicus</i>	BCR	0.4	0.6	0.5	0.3	0.1
		NPV	-\$4 386	-\$2 790	-\$3 691	-\$5 352	-\$6 872
	<i>Bos taurus</i>	BCR	27.6	44.4	35.6	19.1	3.7
		NPV	\$194 604	\$318 101	\$253 169	\$132 356	-\$20 053
	<i>Bos indicus</i>	BCR	0.5	0.9	0.7	0.4	0.1
		NPV	-\$3 424	-\$1 106	-\$2 177	-\$4 422	-\$6 630
	<i>Bos taurus</i> / <i>Bos indicus</i>	BCR	2.2	3.5	2.9	1.6	0.4
		NPV	\$8 769	\$18 279	\$13 788	\$4 531	\$4 494

Source: Carter and Rolls (2014).

3.7 Conclusion

According to the definition of an economically important disease provided for by Mukhebi (1996), the studies reviewed in Section 3.2 indicate the importance of bovine babesiosis. In South Africa, no conclusive economic information concerning the impact of bovine babesiosis exists despite its 35 year old title of economic importance. It is, however, largely accepted as one of the most, if not the most, economically important tick-borne disease amongst the stakeholders of the cattle industry. Furthermore, the economic impact of bovine babesiosis is often provided as the sum of its impact and that of anaplasmosis. Thus, adding to the challenge of having a greater understanding of the economic impact that bovine babesiosis inflicts on the beef industry of South Africa. Frameworks to assess the economic impact of livestock diseases on production have been developed and are continuously adapted to fit the needs of those requiring impact assessments. The theory

supporting methods to value the impacts of disease on production and assessing the economical or financial potential of control strategies were discussed in Section 3.3. However, despite the availability of these frameworks, calculations relating to the impact of bovine babesiosis at the national, regional and individual livestock holder are difficult to achieve due to the complexity of agriculture comprised by variables such as geography; endemic stability; production systems; creating difficulties in collecting relevant and reliable data in light of the available literature discussed in Section 3.4 and 3.5 and may further result in inaccurate assessments (Rushton, 2009:197). Resultantly, contributing to the few studies concerned with the control strategies of bovine babesiosis and the other tick borne diseases reviewed in Section 3.6. In Section 3.6, cost-benefit analyses are the most popular economic tool used for the assessment of tick-borne disease control strategies. The theory in assessing the impact of livestock disease and the production effects reviewed in Section 3.3, 3.4 and 3.5 as well as the economic analysis tools and their indicators used to assess the feasibility of tick-borne disease control strategies in cattle farming reviewed in Section 3.6 contribute towards the development of the production model, economic impact assessment and financial analysis of this study presented in Chapter 4.

Chapter 4

Methods and materials

4.1 Introduction

Succeeding the review of the existing frameworks used for the impact assessments of production disease reviewed in Chapter 3, this chapter describes the development of the model used in exploring the financial implications of bovine babesiosis corresponding to two different dipping strategies. Since field trials have not been executed to aid this research, a dynamic stochastic simulation model is developed. The theory supporting systems modelling, typical farm theory, the development phase and the general assumptions assumed for the development of the model and the respective simulations are explained. The production and the accompanying financial component, as well as the production effects and the associated failure and preventive costs are described in Section 4.3. Selected production effect parameters are built into the model where sufficient published literature exists, as reviewed in Section 3.4. Production effect parameters pertaining to certain factors reviewed in Section 3.4 were excluded from model development due to the lack of published literature. Section 4.4 describes the typical farm in the KwaZulu-Natal Midlands on which the model is developed on. It further redefines the dipping strategies found within the typical farm. Various scenarios of disease prevalence are also described in this section. Data incorporated into the model and methods of data collection are discussed in Section 4.5. The methodology for the economic impact assessment and financial analysis is described in Section 4.6. The chapter is concluded with Section 4.7 discussing the altering of default input parameters for the sensitivity analysis.

4.2 Model development

4.2.1 Systems modelling defined

A system is referred to as the grouping of collected components and their interrelationships within the real world for the purpose of a study. Component selection depends on the objectives of the study in order to represent our simplified view of reality (Jones and Luyten, 1998). System modelling is nothing more than the mathematical representation of the selected components and

their interrelationships (Turner, Rhoades, Tedeschi, Hanagriff, McCuiston, and Dunn, 2013).

4.2.2 Typical farm applications

The typical farm model was identified as the best fit theory in order for the design of this exploratory research. Conducting farm level analyses requires the collection of data. Data may be collected from individual farms or samples of farms, or the use of aggregate state or regionally reported data may be used. In the case of the current study published data exists but is scarce. The development of a typical farm model can assist in alleviating this problem where the simulated data can be representative of farms within a specific area (Feuz and Skold, 1992). The scope of a typical farm model is not for the direct application to a specific farm, nor to provide direct managerial guidance. It is rather used for the evaluation and comparison of different managerial decisions and options. Furthermore, it does allow for the producers within the area of interest to associate themselves with the method adopted (Hoffmann, 2010).

4.2.3 Development phase

The statement of objectives and assumptions about the model boundaries were primarily included in the developmental phase. Using R Studio (RStudio Team, 2016), a dynamic stochastic model was developed to simulate on-farm activities with direct relation to the production of beef weaners intended for sale, the transmission of *Babesia bigemina* and *Babesia bovis* through less intensive dipping strategies in comparison with intensive programmes and the resulting cash flows of these activities, as well as the production losses. Cash flow results including disease related cash flows for either dipping strategy were compared. The economic impact of either dipping strategy according to the definition of Hogeveen and van der Voort (2017) were also compared. Within the model, on farm activities are translated into stocks, flows and converters. A stock represents either an abstract or concrete state variable, which may increase or decrease, and is measured at or over a specific period. Flows are defined as the process that transports stock units from one state to the next over time. Flows are always a rate in terms of stock per unit of time. Connectors move information from one element of the system to another (Turner *et al.*, 2013).

4.2.4 General modelling assumptions

The transmission of disease relies largely on climatic conditions, vector population, host population and host movement. Due to the variability of such factors, a hugely complex system is the result. Therefore, for the development of the production and bovine babesiosis simulation and the associated financial components, general assumptions had to be made. These are as follows:

- The number of cows in the breeding herd remains constant at the start of each simulated year
- All breeding cows are bulled in the first three months of the simulation
- Facilities and conditions for pregnancy tests are ideal allowing an average of 100 cows to be tested in an hour (A. Fowler, personal communication. 2017)

- No twin calving occurs
- Abortions are recognized nine months after a cow is covered by the bull
- Replacement heifers enter the system at twenty to twenty-two months of age
- Climatic conditions remain relatively constant for each simulated year
- Vector populations remain relatively constant for each simulated year
- Vector infectivity remains relatively constant, therefore
- The probability of infection does not differ for animals in different states of existence in an iteration because of cattle movement
- The infection rate for an intensive dipping strategy is expected to remain constant
- The infection rate for a strategic dipping is dependent on the breeding herds seroprevalence in the previous year
- The *Babesia* strains are generic
- An infected animals average daily feed intake is zero on day one and gradually increases over the recovery period
- All animals are treated after receiving an infection, except for subclinical infections
- All oxen are sold between the ages of twelve and fifteen months of age
- Heifers are retained until the average age of eighteen months; surplus heifers are sold after the number of replacement heifers needed are identified
- The immunity status of purchased replacement heifers is unknown and determined stochastically.

4.3 Model construction, segmentation and description

The model is constructed by four distinct, yet highly correlated components. The first component of the model simulates the basic system of a breeding herd and the production of weaners intended for sale and replacement. The second component simulates the cash inflows and outflows associated with the production of beef weaners simulated in the first component. The third component simulates the production effects of a beef weaner producing herd when challenged with a defined prevalence of *Babesia bigemina* or *Babesia bovis* and one of either two dipping strategies adopted. The fourth component models the change in cash outflows, inflows and production costs as a result of the incorporated production effects of bovine babesiosis per parasite challenge.

4.3.1 The production simulation component

The model is of binary nature meaning that each state is either represented by one or zero, where the former equates to true and the latter to false. The probability of each state occurring is calculated by a binomial distribution

$$B(n, P) \quad (1)$$

where

- n is the number of trials
- P is the success probability of each trial.

Each iteration (i) is representative of a yearly time step. The model is initialised with the number of stocks to be simulated in which a herd is comprised of. A cow-space (CS) is synonymous of a stock. Each cow is recorded with their respective age to be used later in the financial component. The proportion of the herd in each age class at the beginning of the simulation is dependent on the maximum number of calving seasons a cow in the herd has been present for. The model can account for a group of cattle of a uniformly distributed age or one that consists of dynamically distributed ages. The initial proportion of the herd in each age class is estimated in accordance with the replacement rate. The replacement rate is estimated in accordance with the rate at which cows may be unable to conceive, or abort, or lose a calf before the end of the year are culled and the annual mortality rate. The replacement rate (rr) is

$$rr = 1 - \left((1 - mc) \times cc \times (1 - ca) \times \left(1 - \frac{mv}{12} \times 3 \right) \right) \quad (2)$$

where

- mc is the yearly mortality rate of breeding cows.
- cc is the conception rate
- ca is the abortion rate
- mv is the yearly mortality rate in calves.

The age of a cow increases in relation to the number of seasons she has calved. With the assumption that a cow can be culled over a period of three months and that the gestation period is nine months, replacement heifers entering the system may vary with age by three months. Therefore, the age categories of the herd are calculated dependently on the number of calving seasons a cow is kept for in the system. Cows that surpass the number of desired breeding seasons are culled and are not included in the replacement rate. The proportion of the herd in each age

category can be calculated beginning with the estimated number of replacement heifers entering the system. It assumes that the replacement rate is held constant for each year as

$$C_1 = \frac{CS}{1 + \sum_{s=1}^{s_{max}-1} (1 - rr)^s} \quad (3)$$

where

- C_1 is the estimated number of cows (i.e. replacement heifers) entering the system for their first season of calving and are, therefore, the youngest cows of the herd
- CS is the number of cow-spaces
- s_{max} is the maximum number of calving seasons a cow is kept for.

From Equation 4, it is possible to estimate the number of cows entering their respective season of calving. Let $S_1 = C_1$, then

$$S_s = S_1 \times (1 - rr)^{s-1} \quad (4)$$

$$SC = (S_1, S_s, \dots, S_{s_{max}}) \quad (5)$$

where

- S_s is the number of cows grouped by the s^{th} season of calving
- s is a sequence along s_{max}
- SC is a vector containing the number of cows according to the number of calving seasons present

therefore

$$CS = \sum SC \quad (6)$$

With Equation 5, the ages of each cow can be determined. The age of a cow in S_1 at the start of the simulation is determined as per the general assumptions, see Section 4.2.4. Therefore, the age of a cow belonging to a calving season group S_s can be determined. Let $S_{1,a,j} = 20 \mid 21 \mid 22$, where (j) represents an individual cow and its age (a) , then the age of a cow belonging to its respective calving season $(S_{s,a,j})$ is

$$S_{s,a,j} = S_{s-1,a,j} + 12 \quad (7)$$

The production simulation component is composed of two sub-components. The first sub-component includes the breeding herd and the suckling calves. The second sub-component includes the weaners. Equations 1 through to 7 allows for the breeding cows to be initialised. Calves born in the previous year before model simulation are included in the first sub-component. These calves are recognised as calves for the first third of the year. The probable number of calves starting the simulation is dependent of the replacement rate (rr) and is estimated with Equation 8. The number of weaners initialising the model is dependent of mortality rate of cows (mc), mortality rate of calves (mv), conception rate (cc), abortion rate (ca), weaner mortality rate (mw) and the gender distribution rate (g). All oxen are sold by the end of each year in which calves are weaned. Heifers are retained for replacement and the surplus are sold in the following year. The weaner sub-component that initialises the model are therefore only heifers and is estimated with Equation 9.

$$Y_{calf} = B(CS, 1 - P_{rr}) \quad (8)$$

$$Y_{weaner} = B(CS, P_{cc} - P_{ca} - P_{mc} - P_{mv} - P_{mw} - P_g) \quad (9)$$

where

- Y_{calf} is the number of calves at the start of the simulation
- Y_{weaner} is the number of heifers at the start of the simulation.

Once the model has been initialised, it is permitted to run. The model is dependent on the following variables and input parameters defined in Table 4.1.

The model is iterated by the number of simulation years. Each breeding cow in a cow-space is set to 1 representing an alive state with their respective age determined by Equation 7. The probability of a cow remaining alive due to the mortality rate is estimated by Equation 10. Where $BC_{i,j} = 1$ the cow remains alive, else $BC_{i,j} = 0$ the cow has died.

$$BC_{i,j} = B(BC_{i,j}, 1 - P_{mc}) \quad (10)$$

Once the probability of a cow remaining alive is determined, the following model stock variables can be estimated. Each cow has a probability of being culled over a period of three months, which in turn determines whether she is an early-, mid- or late-calver. Culling occurs at the start of every iteration after the incidence of mortality has occurred. It is assumed that every cow which remains alive is culled. The probability of a cow being culled in the first (P_{be}), second (P_{bm}) and third (P_{bl}) month, represented by the variables BE , BM and BL , are estimated by equation 11, 12 and 13, respectively.

$$BE_{i,j} = B(BC_{i,j}, P_{be}) \quad (11)$$

$$BM_{i,j} = \begin{cases} 0, & \text{if } BE_{i,j} = 1 \\ B(BC_{i,j}, P_{bm} + P_{be}), & \text{if } BE_{i,j} = 0 \end{cases} \quad (12)$$

$$BL_{i,j} = \begin{cases} 0, & \text{if } BE_{i,j} \text{ or } BM_{i,j} = 1 \\ B(BC_{i,j}, P_{bl} + P_{bm} + P_{be}), & \text{if } BE_{i,j} \text{ and } BM_{i,j} = 0 \end{cases} \quad (13)$$

Table 4.1: Description of the production simulation component variables and parameters.

Variable/Parameter	Description	Unit
<i>Simulation variables</i>		
SY	Simulation years	Years
i	Year in simulation years	Year
CS	The number of breeding cows simulated (cow-spaces)	Numeric
j	Animal in cow-space	Numeric
<i>State of existence variables [E]</i>		
BC	Breeding cows during the year	Numeric
$Xcalf$	Calves in the last quarter of the year	Numeric
$Ycalf$	Calves in the first third of the year	Numeric
$Xweaner$	Weaners in the last two thirds of the year	Numeric
$Yweaner$	Heifers in the first quarter of the year	Numeric
<i>Input parameters</i>		
be	Bulled early	%
bm	Bulled mid	%
bl	Bulled late	%
mc	Mortality rate of cow	%
cc	Conception rate	%
ca	Abortion rate	%
mv	Mortality rate of calf	%
mw	Mortality rate of weaner	%
g	Gender rate	%
CuN	Threshold age at which cows are identified as culls	Month

All cows are pregnancy tested in the fourth month. The probability of a cow conceiving is determined by the conception rate. If a cow fails to conceive, the cow is culled.

$$Preg_{i,j} = B(BC_{i,j}, P_{cc}) \quad (14)$$

$$CuPreg_{i,j} = \begin{cases} 0, & \text{if } Preg_{i,j} = 1 \\ 1, & \text{if } Preg_{i,j} = 0 \text{ and } BC_{i,j} = 1 \end{cases} \quad (15)$$

where

- *Preg* is the variable representing an alive cow having conceived
- *CuPreg* is the variable representing an alive cow having failed to conceive, and therefore will be culled.

The event of a calf being born is determined after a cow has conceived and the abortion rate. Failing to deliver a calf due to reasons of abortion will result in the removal from the herd and is culled at the end of the iteration.

$$born_{i,j} = B(Preg_{i,j}, 1 - P_{ca}) \quad (16)$$

$$CuAbort_{i,j} = \begin{cases} 0, & \text{if } born_{i,j} = 1 \\ 1, & \text{if } born_{i,j} = 0 \text{ and } Preg_{i,j} = 1 \end{cases} \quad (17)$$

where

- *born* is the variable representing a pregnant cow having given birth to a calf
- *CuAbort* is the variable representing a pregnant cow having aborted a calf, and therefore will be culled.

Having determined when a cow was bulled by Equation 11, 12 and 13, the model allocates a month of birth (*MB*) to a new born calf. *MB* is determined by Equation 18. Furthermore, Equation 19 determines the probability of a new born calf (*Xcalf*) remaining alive until the end of a year in concurrence with *MB* and the probability of calf mortality (P_{mv}).

$$MB_{i,j} = \begin{cases} 10, & \text{if } BE_{i,j} = 1 \\ 11, & \text{if } BM_{i,j} = 1 \\ 12, & \text{if } BL_{i,j} = 1 \end{cases} \quad (18)$$

$$Xcalf_{i,j} = B\left(born_{i,j}, 1 - \left(\frac{P_{mv}}{12} \times (13 - MB_{i,j})\right)\right) \quad (19)$$

A cow is culled if it fails to rear a calf until the end of an iteration, during the last quarter of the year. However, a cow is not culled if it fails to rear a calf in the following iteration, during

the first third of the year that calves are still suckling. This is due to the probability that the cow may have conceived during the three month period a cow may be culled. The culling of a cow which fails to rear a calf during the last quarter of the year is represented by the variable $CuCalf$ and determined by Equation 20.

$$CuCalf_{i,j} = \begin{cases} 0, & \text{if } Xcalf_{i,j} = 1 \\ 1, & \text{if } Xcalf_{i,j} = 0 \text{ and } born_{i,j} = 1 \end{cases} \quad (20)$$

A month of removal (MR) is assigned to a cow as a result of it being culled or to a cow which dies as a result of the mortality rate. Cows that are culled for reasons of failed conception, abortion or failing to rear a calf before the end of an iteration are allocated a fixed month of removal. Where a cow is removed from the simulation as a result of mortality, a random month of death is determined by a uniform distribution. A uniform distribution is continuous with an equal probability along the identical interval length of the distributions support. Two parameters identify the support. The prior parameter is the minimum (a), the latter; the maximum (b). Intervals of one month are used. Parameter a is defined as the minimum number of months an animal may exist in a state of being alive, whereas b is the maximum. The uniform distribution is denoted as

$$U(a, b) \quad (21)$$

therefore

$$MR_{i,j} = \begin{cases} U(1, 12), & \text{if } BC_{i,j} = 0 \\ 4, & \text{if } CuPreg_{i,j} = 1 \\ 10, & \text{if } CuAbort_{i,j} = 1 \text{ and } BE_{i,j} = 1 \\ 11, & \text{if } CuAbort_{i,j} = 1 \text{ and } BM_{i,j} = 1 \\ 12, & \text{if } CuAbort_{i,j} = 1 \text{ and } BL_{i,j} = 1 \\ 12, & \text{if } CuCalf_{i,j} = 1 \end{cases} \quad (22)$$

An important feature of the model is that it can record the age of an individual animal; breeding cow, calf, or weaner. An age benchmark for an individual permits the distribution of weights to each animal depending on which age class category it falls within. A feature of the model which is used for the sale of animals, see Section 4.3.2, and the infection of animals during and after their non-specific immunity, see Section 4.3.3. A breeding cow may pass through six age class categories, where as a weaner, oxen or heifer, intended for sale will only pass through the first two. The six age class categories (k), Calf, Weaner, A, AB, B and C, are illustrated in Figure 4.1.

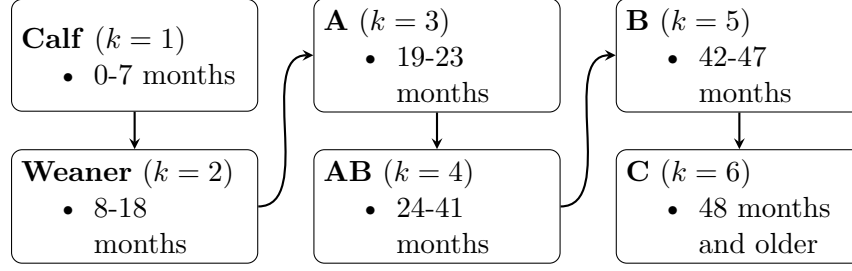


Figure 4.1: Flow diagram of age class category transfer.

The age of a breeding cow ($AgeCow$) that remains alive at the end of an iteration will naturally increase by twelve months. Alternatively, the age of an animal which dies or is culled will increase by MR and is denoted by Equation 23.

$$AgeCow_{i,j} = \begin{cases} AgeCow_{i-1,j} + 12, & \text{if } BC_{i,j} = 1 \\ AgeCow_{i-1,j} + MR_{i,j}, & \text{if } CuPreg_{i,j} \text{ or } CuAbort_{i,j} \text{ or } CuCalf_{i,j} = 1 \end{cases} \quad (23)$$

Cows having reached the age expected (CuN) at the end of the s_{max} calving season are removed from the herd and culled after weaning. These cows ($CuAged$) are recognised at the end of an iteration and removed from the following iteration after their calves have been weaned from them. Therefore,

$$CuAged_{i,j} = 1 \text{ where } AgeCow_{i-1,j} \geq CuN - 12 \quad (24)$$

Recognising the cows which have been culled for either one of the various reasons, the variable representing an alive state (BC) is reset to zero. The variable is reset in order for the model to determine the number of replacement heifers needed in the following iteration in order to keep the herd at a stable population of CS .

$$BC_{i,j} = \begin{cases} 0, & \text{if } CuPreg_{i,j} = 1 \\ 0, & \text{if } CuAbort_{i,j} = 1 \\ 0, & \text{if } CuCalf_{i,j} = 1 \\ 0, & \text{if } CuAged_{i,j} = 1 \end{cases} \quad (25)$$

Calves denoted as $Ycalf$, are those born in the previous year which start the current. The probability of calf mortality (P_{mv}) is calculated during the period that a calf is recognised as a calf during the contemporaneous iteration. At the end of the fourth month, equating to seven months after the first calves were born, the remaining calves are transferred to the weaner herd. This is in accordance with the pregnancy test of the breeding cows. The probability of a calf being weaned

is dependent of the calf's state of existence in the previous iteration.

$$Ycal f_{i,j} = B \left(Xcal f_{i-1,j}, 1 - \left(\frac{P_{mv}}{17 - MB_{i-1,j}} \times 4 \right) \right) \quad (26)$$

The age of a calf at weaning is determined. Similarly to the death of a cow, the age of a calf which dies before weaning is determined by the uniform distribution.

$$AgeYcal f_{i,j} = \begin{cases} 17 - MB_{i-1,j}, & \text{if } Ycal f_{i,j} = 1 \\ 17 - MB_{i-1,j} - U(1, 3), & \text{if } Ycal f_{i,j} = 0 \end{cases} \quad (27)$$

After weaning, no calves are present in the breeding herd model until the tenth month. The new-born calves enter the model in the tenth, eleventh and twelfth months as determined by equation 16 and the probability of the calf remaining alive until the end of the iteration by Equation 19. The age of a new-born calf ($AgeXCalf$) is determined in concurrence with MB whether it remains alive. Else, the uniform distribution determines the age of the calf if it dies.

$$AgeXCalf_{i,j} = \begin{cases} 13 - MB_{i,j}, & \text{if } Xcal f_{i,j} = 1 \\ U(1, 3), & \text{if } Xcal f_{i,j} = 0 \end{cases} \quad (28)$$

Calves completing their state as $Ycalf$ are transferred from the breeding herd and enter the weaner herd during the same year. New weaners are denoted as $Xweaner$. These weaners consist of both oxen and heifers, not yet recognised by the model. The probability of a weaner remaining alive (P_{mw}) until the end of an iteration is determined by Equation 29 and the probability of gender (P_g) by Equation 30 and 31.

$$Xweaner_{i,j} = B \left(Ycal f_{i,j}, 1 - \left(\frac{P_{mw}}{12} \right) \times 8 \right) \quad (29)$$

$$Heifer_{i,j} = B(Xweaner_{i,j}, P_g) \quad (30)$$

$$Ox_{i,j} = \begin{cases} 0, & \text{if } Xweaner_{i,j} = 1 \text{ and } Heifer_{i,j} = 1 \\ 1, & \text{if } Xweaner_{i,j} = 1 \text{ and } Heifer_{i,j} = 0 \end{cases} \quad (31)$$

where

- $Heifer$ is the variable representing weaners as heifers

- Ox is the variable representing the weaners as oxen.

The age of a new weaner ($AgeXweaner$) is determined according to whether it is alive or not. The age of a weaner that remains alive at the end of an iteration is determined in concurrence with the age it was when weaned and the number of months it is recognised as a weaner until year end. Where as the age of a weaner which dies is calculated with the addition of the uniform distribution.

$$AgeXweaner_{i,j} = \begin{cases} AgeYcalf_{i,j} + 8, & \text{if } Xweaner_{i,j} = 1 \\ AgeYcalf_{i,j} + U(1, 8), & \text{if } Xweaner_{i,j} = 0 \end{cases} \quad (32)$$

Oxen are sold during the ninth through to the twelfth month of the contemporaneous year. The sale of oxen is discussed in more detail in Section 4.3.2. Heifers are retained for the following year in order to replace the breeding cows which are removed in the current year. Surplus heifers are sold. Therefore, the probability of a heifer ($Yweaner$) remaining alive until the time of sale or the decision to retain it as a replacement heifer is dependent on the heifers available in the previous year. The decision of the number of replacement heifers is determined in the third month. The age of a heifer ($AgeYweaner$) is determined by whether it remains alive at the time of sale and replacement or if it dies.

$$Yweaner_{i,j} = B\left(Heifer_{i,j}, 1 - \left(\frac{P_{mw}}{12}\right) \times 3\right) \quad (33)$$

$$AgeYweaner_{i,j} = \begin{cases} AgeXweaner_{i-1,j} + 3, & \text{if } Yweaner_{i,j} = 1 \\ AgeXweaner_{i-1,j} + U(1, 3), & \text{if } Yweaner_{i,j} = 0 \end{cases} \quad (34)$$

The number of replacement heifers needed for the herd to remain at a stable number of CS in the following year is dependent of the number of breeding cows removed from the simulation in the current year. The number of replacement heifers required (RN_i) is determined at the end of an iteration. Therefore,

$$RN_i = CS - \sum_{j=1}^{CS} BC_{i,j} \quad (35)$$

In years where the number of RN is less than or equal to the sum of the available heifers, the number of retained heifers (RT) will equate to RN . Surplus heifers are sold in the third month at the average age of eighteen months old. Weights of the heifers at the time of sale are estimated

by a random normal distribution. Surplus heifers sold is further discussed in Section 4.3.2.

$$RT_i = RN_i \text{ where } RN_i \leq \sum_{j=1}^{CS} Y_{weaner_{i,j}} \quad (36)$$

However, in years where RN is less than the total number of available heifers, the number of retained heifers will equate to the sum of the available heifers. The deficit (D) number of heifers is recorded and purchased.

$$RT_i = \sum_{j=1}^{CS} Y_{weaner_{i,j}} \text{ where } RN_i > \sum_{j=1}^{CS} Y_{weaner_{i,j}} \quad (37)$$

then

$$D_i = RN_i - \sum_{j=1}^{CS} Y_{weaner_{i,j}} \quad (38)$$

Therefore, the number of replacement heifers (RH) entering the breeding herd in the following iteration is as follows.

$$RH_{i+1} = RT_i + D_i \quad (39)$$

Figures 4.2, 4.3 and 4.4 schematically illustrates the flow of breeding cows, calves and weaners, respectively, within the model.

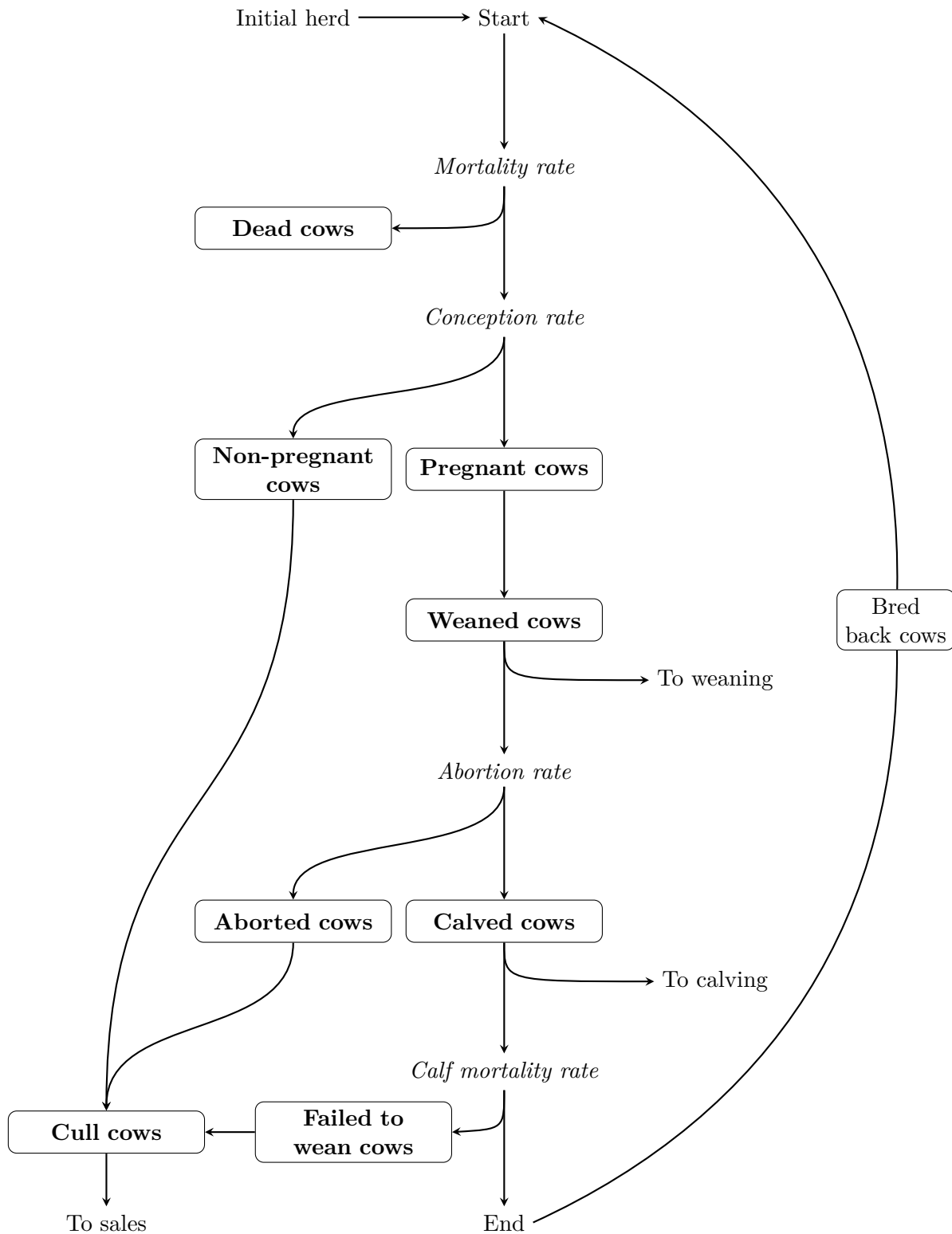


Figure 4.2: Flow diagram of breeding herd representing 1 iteration (i) for 1 year.

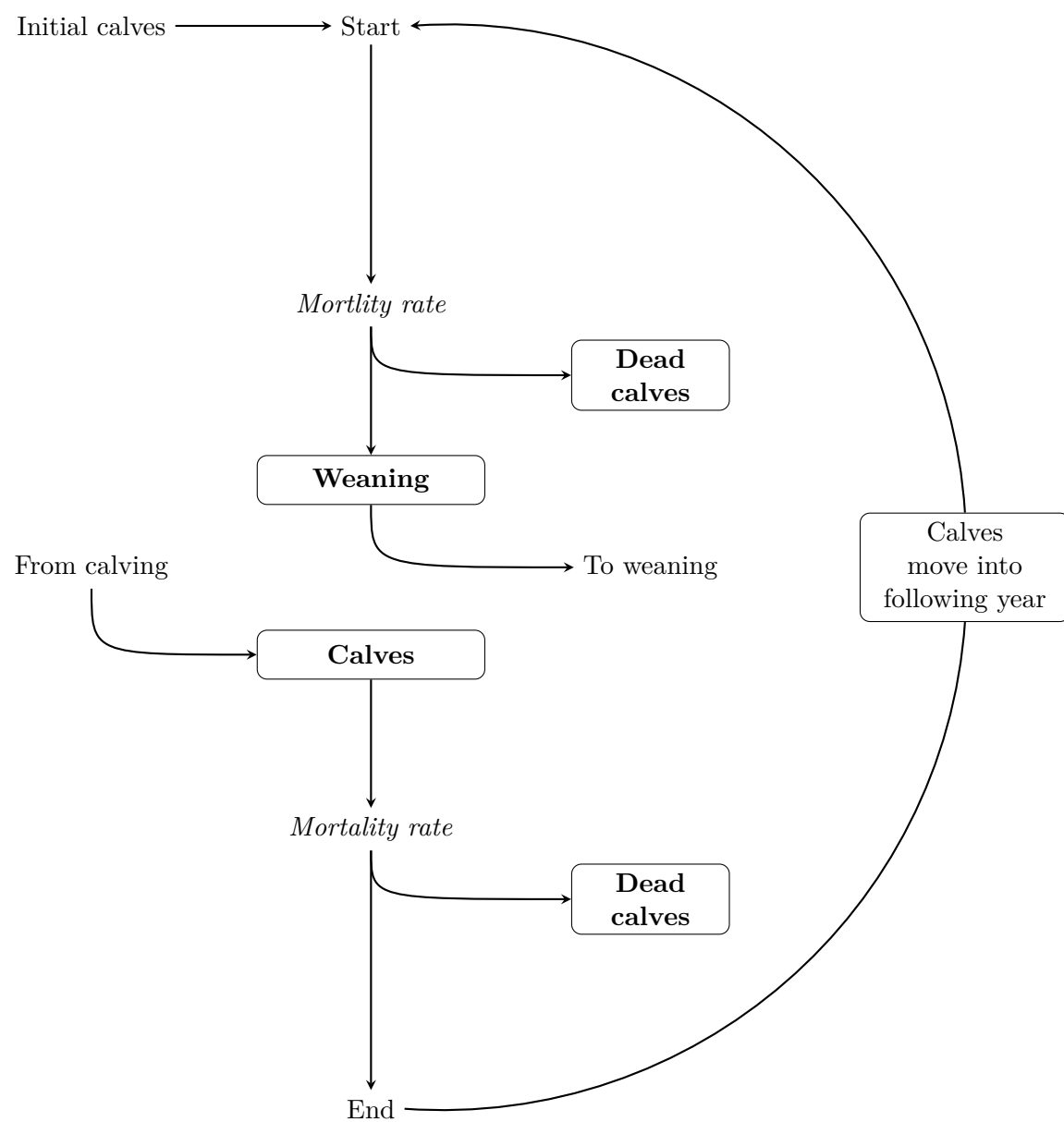


Figure 4.3: Flow diagram of calves representing 1 iteration (i) for 1 year.

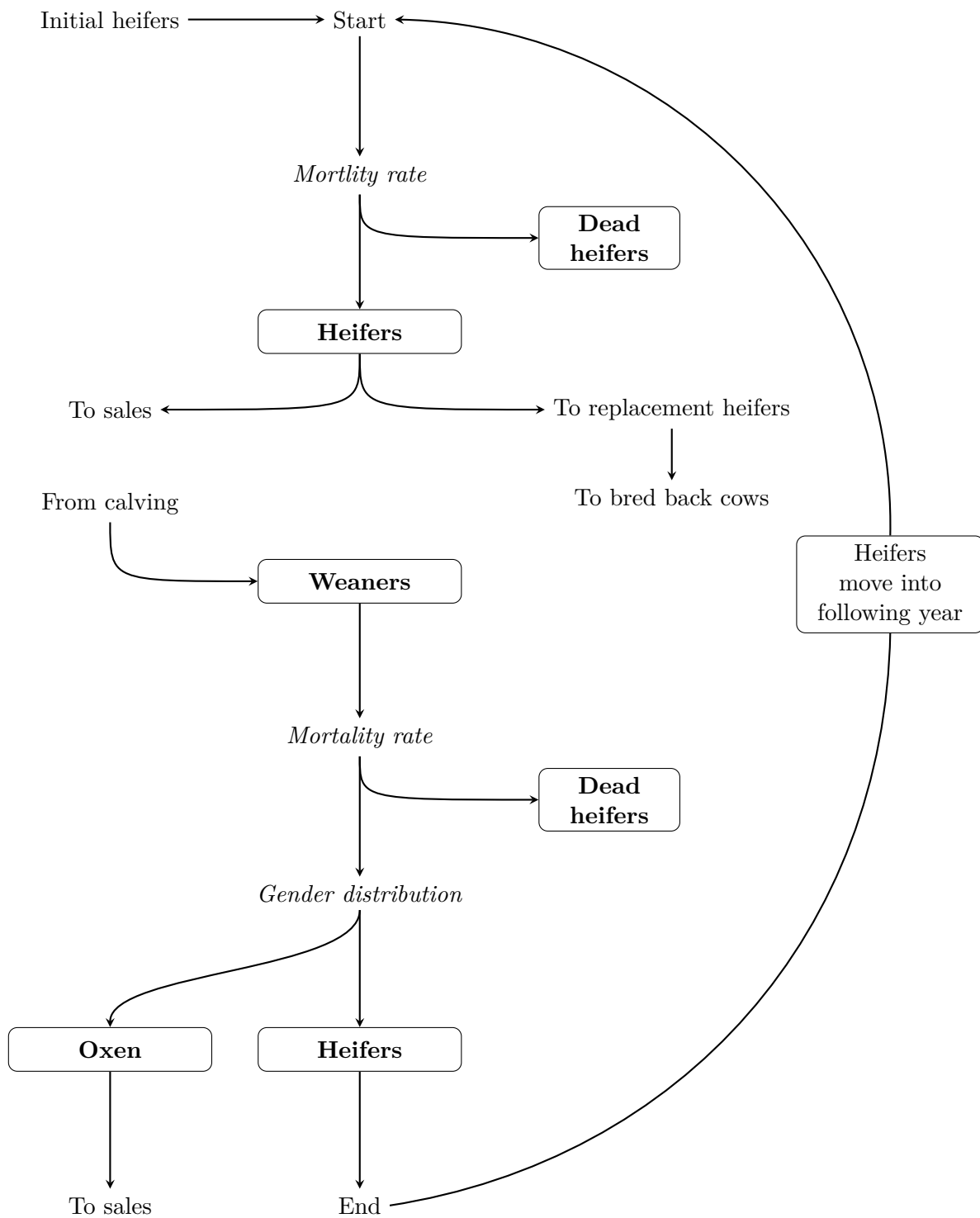


Figure 4.4: Flow diagram of weaners representing 1 iteration (i) for 1 year.

4.3.2 The financial component

The financial component of the model considers only the inflow and outflow of cash related to the production of beef weaners. Inflow is yielded from the sale of oxen, heifers and cull cows. The sum of the expenditures yields the cash outflow. Expenditures are comprised of two production cost component variables, namely feed and pregnancy testing. The inflows and outflows are shown at year end. However, they are calculated according to the indicated period an animal is present for in a year. Furthermore, the expenses are estimated in relation to an animal in either one of the six age class categories. The financial simulation component input parameters are described in Table 4.2.

Table 4.2: Financial simulation component input parameters and descriptions.

Parameter	Description	Unit
<i>Revenue</i>		
μW_k	Mean weight of an animal in age class category k	kg
σW_k	Standard deviation of an animals weight in age class category k	kg
$\mu Price_k$	Mean market price per kilogram for an animal in age class category k	ZAR/kg
<i>Expenses</i>		
pt	Cost of pregnancy testing per herd size of 100 cows	ZAR/hour
f	Feed type fed to an animal in a year	
$feedcost_f$	Cost of feed	ZAR/kg
$ADFI_{f,k}$	Average feed intake of feed type f per animal in age class category k	kg
$plantcost$	Cost of planting pasture per hectare	ZAR/ha
SR	Stocking rate per hectare	Animal/ha
GP	Number of days intended for grazing	Days
$feedmonth_{f,k}$	Period length an animal in age class category k is fed feed type f	Month

Animals weights prepared for sale, either beef weaners or cull cows, are simulated by a normal distribution. A normal distribution is denoted as:

$$\mathcal{N}(\mu, \sigma^2) \quad (40)$$

where

- μ is the mean
- σ^2 is the variance.

With Equation 31 having determined whether a weaner is an ox or not, the simulation of revenue received from the sales of oxen (*SalesOxen*) is permitted, as in Equation 41. Oxen are

sold in either month from the ninth through to the twelfth.

$$SalesOxen_i = \sum_{j=1}^{CS} \left(Ox_{i,j,k} \times \mathcal{N}(\mu W_k, \sigma W_k^2) \right) \times \mu Price_k \quad (41)$$

The number of heifers retained as replacement heifers are determined by Equation 36 and 37. Where the number of retained heifers is less than the sum of the available heifers, a surplus of heifers will exist. The surplus heifers are sold. The revenue received from sale of surplus heifers (*SalesHeifers*) is calculated in concurrence with the surplus and a normal distribution using the average weights and price of the A class category, where $k = 3$. Else, no revenue is received from the sale of heifers if the number of retained heifers is greater or equal to the total available amount of heifers, as in Equation 37.

$$SalesHeifers_i = \left(\left(\sum_{j=1}^{CS} Yweaner_{i,j} \right) - RT_i \right) \times \mathcal{N}(\mu W_3, \sigma W_3^2) \times \mu Price_3 \quad (42)$$

Breeding cows recognised as culls are primarily identified by their age. The recognition of a cull cow's age is in order to allocate the correct weight and price parameters before estimating the price received for the sale. The revenue received in each k for cull cows having failed to conceive (*CuPregRev*), having aborted (*CuAbortRev*), having lost a calf before the next season of bulling (*CuCalfRev*) and those which are too old to breed (*CuAgedRev*) are identified by the following equations.

$$CuPregRev_i = \sum_{j=1}^{CS} \left(CuPreg_{i,j,k} \times \mathcal{N}(\mu W_k, \sigma W_k^2) \right) \times \mu Price_k \quad (43)$$

$$CuAbortRev_i = \sum_{j=1}^{CS} \left(CuAbort_{i,j,k} \times \mathcal{N}(\mu W_k, \sigma W_k^2) \right) \times \mu Price_k \quad (44)$$

$$CuCalfRev_i = \sum_{j=1}^{CS} \left(CuCalf_{i,j,k} \times \mathcal{N}(\mu W_k, \sigma W_k^2) \right) \times \mu Price_k \quad (45)$$

$$CuAgedRev_i = \sum_{j=1}^{CS} \left(CuAged_{i,j,k} \times \mathcal{N}(\mu W_k, \sigma W_k^2) \right) \times \mu Price_k \quad (46)$$

As per the general assumption in Section 4.1.3, it is assumed that the facilities are ideal for efficient pregnancy testing. The cost of pregnancy testing ($ExpPregtest$) per year is therefore fixed at 100 cows per hour, regardless of whether any animals die prior to the event. Pregnancy testing occurs in the fourth month in accordance with weaning. Thus, allowing cows which do not conceive to be culled after their calf is weaned.

$$ExpPregtest_i = \frac{pt}{100} \times CS \quad (47)$$

In years where the sum of the available number of heifers is less than the required amount, a deficit will occur. The deficit number of required heifers indicates the number needed for purchase to maintain the breeding herd at a constant number, identified by CS , at the start of each simulation. Purchased replacement heifers are within the A class category, where $k = 3$. The expense incurred due to the purchase of replacement heifers (RP) is estimated in concurrence with Equation 38.

$$RP_i = \sum_{j=1}^{D_i} \mathcal{N}_j \left(\mu W_3, \sigma W_3^2 \right) \times \mu Price_3 \quad (48)$$

The cost of feed supplement ($ExpFeed$) is estimated according to various feed supplement types the cows, calves and weaners consume during a year. These costs are dependent of the cost per kilogram of the supplement, the average amount of a particular feed consumed by an animal per day, and the length of the period an animal is fed for. The expense of feed attributed to an animal which is removed from the simulation for mortality and culling reasons as well as for the oxen sold in a specific month are accounted for accordingly to the month of removal.

$$ExpFeed_i = \sum_{j=1}^{CS} feedcost_{i,j,k,f} \times \sum_{j=1}^{CS} (ADFI_{i,j,k,f} \times 30) \times \sum_{j=1}^{CS} feedmonth_{i,j,k,f} \quad (49)$$

The estimated cost of pasture grazing ($ExpPast$) is dependent on the stocking rate per hectare and the intended grazing period. Pasture expenses are estimated according to the cost per weaner per month and is multiplied by the sum of weaners available.

$$ExpPast_i = \sum_{j=1}^{CS} Xweaner_{i,j} \times \left(\frac{\frac{plantcost}{SR}}{GP} \times 30 \times feedmonth_{f,k} \right) \quad (50)$$

4.3.3 The bovine babesiosis simulation component

Prior to the simulation of the production component, a seroprevalence parameter is assumed. This parameter provides an indication of the breeding herds current level of immunity as

per Norval *et al.* (1983); those cattle which have received an infection and seroconverted. As a result of the simulated production component, an expected number of breeding cows will be removed from the model for reasons of mortality and culling. The loss of animals due to mortality and culling will include immune animals.

The infection rate is estimated once the seroprevalence parameter is defined. Two separate infection rates are included in the model; each are dipping strategy specific. The probability of infection using either infection rate targets only the susceptible animals during an iteration. Susceptible animals are defined as those that have not yet received an infection. Immune animals are disregarded from the risk of infection. Animals that do not succumb to the infection rate will be regarded as susceptible in the following year if they remain.

Eight relative disease states, adapted from Ramsay (1997a), are included in the bovine babesiosis component thought to have an effect on production. The eight states are comprised of four disease severity states which is dependent of the resilience to disease according the cattle breed and age. Animals which befall to an infection are then categorised by one of the four states of disease severity, namely; subclinical infection, mild clinical infection, severe clinical infection and acute infection. A subclinical infection immediately results in immunity and no production effects occur. A mild and severe clinical infection results in adverse production effects, followed by recovery and immunity. Acute infections result in the death of an animal. The animals which seroconverted following an infection with reference to one of either three clinical states are excluded in the following year regarding the probability of infection. Figure 4.5 illustrates the flow of infection, disease severity and immunity.

In Section 2.8, it is understood that the susceptibility to bovine babesiosis differs amongst cattle breeds and in age. Therefore, parameters concerning the disease severity categories are defined according to the *Bos taurus* cross *Bos indicus* breeds. Including only one type of cattle breed and discarding the *Bos taurus* and *Bos indicus* breeds is discussed in finer detail in Section 4.4.1. The age categories are divided by animals younger than nine months whom have a higher level of resistance due to their non-specific immunity and animals ten months and older. The severity of disease is determined with a uniform distribution. Data pertaining to these default input parameters is discussed in Section 4.5.

The inoculation rate, as discussed in Section 2.10, assumes that the daily probability of infection is constant over time (Mahoney (1969) as cited by Ramsay (1997a)). Therefore, the inoculation rate is used as the infection rate for intensive dipping strategies in relation to the assumptions made in Section 4.2.4. The value of the inoculation rate can be estimated using serologic prevalence data for different age groups of cattle. The inoculation rate (h) (Smith, 1991) is expressed as

$$h = \frac{-\ln(1 - sp)}{td} \quad (51)$$

where

- sp is the serologic prevalence of the *Babesia* parasite among the tested breeding cows of the herd

- td is the average age of animals in days.

The incidence risk is defined as the average probability of an animal receiving an infection of a *Babesia* parasite within a year; used in association with the strategic dipping strategy. Reduced dipping allows for the vector population to increase; therefore, it is expected that an outbreak of disease is to occur within the first one to two years after having shifted away from intensive dipping towards strategic dipping (A. Fowler, personal communication. 2018). The incidence risk increases the probability of infection in congruence with the expectation of an outbreak to occur with the decrease of dipping. Ramsay (1997a) used the incidence risk formula to predict disease severity in relation to *Babesia bovis* which further contributed to economic studies assessing disease control strategies and production losses avoided (Ramsay, 1997b; Ramsay, Tisdell and Harrison, 1997c). Ramsay (1997a) identifies the yearly incidence risk (IR) according to Lilienfeld and Lilienfeld (1980) as:

$$IR = 1 - 10^{\log(1-sp) \times ty} \quad (52)$$

where

- sp is the serologic prevalence of the *Babesia* parasite among the tested breeding cows of the herd
- ty is the average age of animals in years.

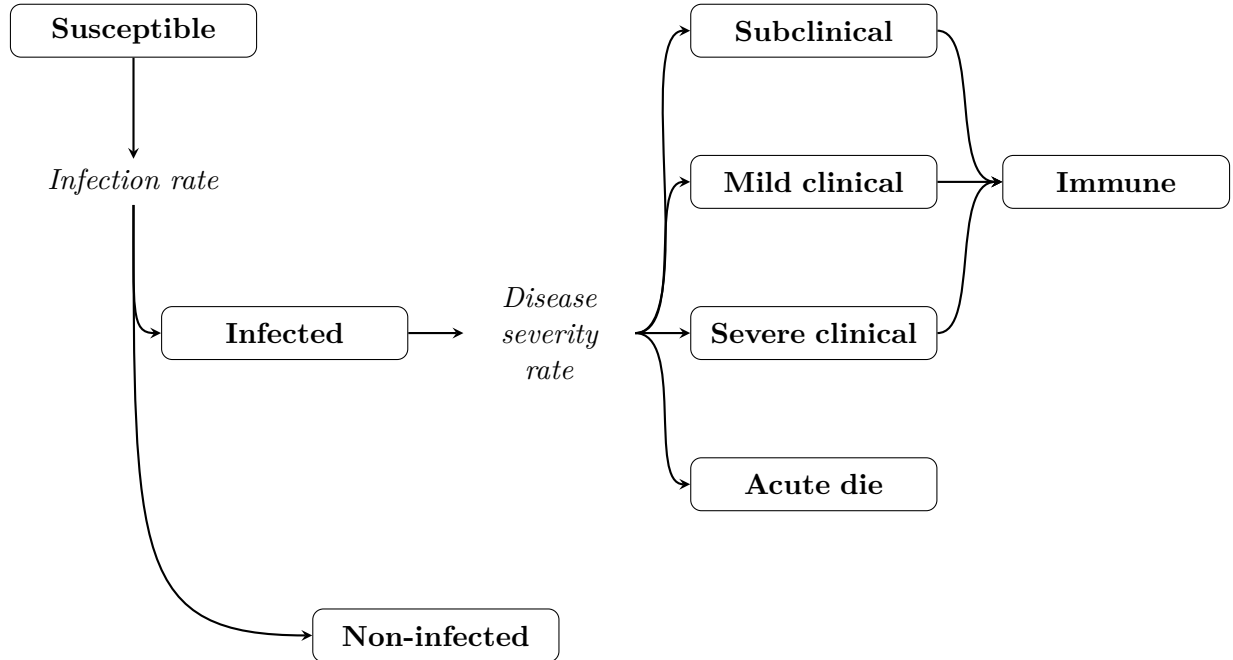


Figure 4.5: Flow diagram of infection and disease severity.

Ramsay (1997a) further defines the incidence risk as the proportion of animals which seroconvert within a year. Therefore, it is important to understand that this formula only considers the seroprevalence in animals that have seroconverted within a year. As the likelihood of mortality ensuing for reasons of a *Babesia* infection and the probability of such an occurrence varies according to cattle breeds and age, the formula discards animals that succumb to such a state. Therefore, the proportion of susceptible animals will decrease due to an increasing level of immunity over time. The incidence risk of infection in a current year is dependent on the seroprevalence of the sum of the animals in a state of existence at the time in which probability parameters are simulated. The incidence risk is therefore adjusted for each simulated year as

$$IR_i = 1 - 10^{\log(1-sp_i) \times ty} \quad (53)$$

The incidence risk is estimated based on the breeding herd's seroprevalence for the start of the first year. The incidence risk is distributed among all states of existence in the first year. Thereafter, the incident risk for weaned calves is dependent on the seroprevalence within the calf cohort being removed from the breeding herd. The incidence risk for each independent weaner cohort is therefore dependent on the seroprevalence of the group. Table 4.3 provide variable and equation descriptions for the bovine babesiosis simulation component.

An animal in either state of existence $[E]$, refer to Table 4.1, is recognised as such for an independent period. Therefore, the period in which an animal in $[E]$ may become infected will differ in comparison with an animal identified in another state of existence. Breeding cows are identified as *BC* for an entire year. Calves born during the last quarter of the year are identified as *Xcalf* for one to three months and calves moving into the following year are identified as *Ycalf* for four months before they are weaned. Calves identified as *Ycalf* are weaned in the current iteration and are then identified as *Xweaner* for the last two thirds of the year. Heifers which remain for replacement decisions are transferred from *Xweaner* in the previous iteration to the current and are recognised as *Yweaner* for the first quarter of the year. Equations 54 to 59 identify the probability of infection for an animal in a state of existence. The probability of infection in a weaner determined by Equation 57 is during the period of non-specific immunity, where as in Equation 58 the weaners have surpassed their non-specific immunity.

$$InfBC_{i,j} = B(BC_{i,j} - ImmBC_{i-1,j}, P_{inf}) \quad (54)$$

$$InfXcalf_{i,j} = B\left(Xcalf_{i,j}, \left(\frac{P_{inf}}{12}\right) \times AgeXcalf_{i,j}\right) \quad (55)$$

$$InfYcalf_{i,j} = B\left(Ycalf_{i,j} - ImmXcalf_{i-1,j}, \left(\frac{P_{inf}}{12}\right) \times 4\right) \quad (56)$$

$$InfXweaner_{i,j} = B \left(Xweaner_{i,j} - ImmYcalf_{i,j}, \left(\frac{P_{inf}}{12} \right) \times (9 - AgeYcalf_{i,j}) \right) \quad (57)$$

$$InfXweaner_{i,j} = B \left(Xweaner_{i,j} - InfXweaner_{i,j}, \left(\frac{P_{inf}}{12} \right) \times (AgeYcalf_{i,j} - 1) \right) \quad (58)$$

$$InfYweaner_{i,j} = B \left(Yweaner_{i,j} - ImmXweaner_{i-1,j}, \frac{P_{inf}}{12} \times 3 \right) \quad (59)$$

where

- *InfBC* is the variable representing infected breeding cows
- *InfXcalf* is the variable representing infected calves in the last quarter of the year
- *InfYcalf* is the variable representing infected calves in the first third of the year
- *InfXweaner* is the variable representing infected weaners in the last two thirds of the year
- *InfYweaner* is the variable representing infected weaners in the first quarter of the year.

An animal in any of the states of existence becomes immune following a recoverable infection. If an immune animal remains in the simulation for more than two years, immunity from the previous year is transferred to the following. If the probability of infection in an animal in $[E]$ is true, variables identifying the disease severity (ds) and immunity (Imm) are determined. Since ds and Imm apply to any infected animal in $[E]$, the following equations are identified where $[E]$ holds position for the infected animal in the state of existence at question. Therefore, the uniform distribution identifies ds as

$$ds[E]_{i,j} = U(0, Inf[E]_{i,j}) \quad (60)$$

subsequently, the acquisition of immunity for an animal in $[E]$ is

$$Imm[E]_{i,j} = 1 \text{ where } 0 < ds[E]_{i,j} \leq suc_{d,z} + mic_{d,z} + sec_{d,z} \quad (61)$$

else, the animal in $[E]$ is identified as dead as in Equation 61.

$$[E]_{i,j} = 0 \text{ where } suc_{d,z} + mic_{d,z} + sec_{d,z} < ds[E]_{i,j} \leq 1 \quad (62)$$

Table 4.3: Description of bovine babesiosis simulation component parameters.

Parameter	Description	Unit
sp	Seroprevalence	%
inf	Probability of infection during the year; defined by the dipping strategy	%
$suc_{d,z}$	Probability of subclinical infection of parasite d^* in animal in state of non-specific immunity z^{**}	%
$mic_{d,z}$	Probability of a mild clinical infection of parasite d with recovery in animal in state of non-specific immunity z	%
$sec_{d,z}$	Probability of a severe clinical infection of parasite d with recovery in animal in state of non-specific immunity z	%
$acd_{d,z}$	Probability of an acute infection of parasite d resulting in death in animal in state of non-specific immunity z	%
$mri_{d,z}$	Minimum recovery period of an animal suffering from a mild clinical infection of parasite d in state of non-specific immunity z	day
$mrxd_{d,z}$	Maximum recovery period of an animal suffering from a mild clinical infection of parasite d in state of non-specific immunity z	day
$sri_{d,z}$	Minimum recovery period of an animal suffering from a severe clinical infection of parasite d in state of non-specific immunity z	day
$srx_{d,z}$	Maximum recovery period of an animal suffering from a severe clinical infection of parasite d in state of non-specific immunity z	day

* The probability of disease severity estimated for the infection type, either *Babesia bigemina* or *Babesia bovis*, is denoted by subscript d ; tables B.1 - C.2.

** The probability of disease severity estimated for animals 9 months and younger or older than 9 months is denoted by subscript z ; tables B.1 - C.2.

4.3.4 The failure and preventive costs component

With cognizance of the effect bovine babesiosis has on an animal, the production losses and the associated failure and preventive costs could then be modelled. Failure costs are modelled according to each naive animal succumbing to an infection. All infected animals, except those suffering subclinical infections, are treated once with the prescribed drugs necessary. The cost of treatment for an infected animal $Treat[E]_{i,j}$ is estimated according to the cost of a treatment tr_n of type n per kilogram of live weight and it's weight.

$$Treat[E]_{i,j} = \mathcal{N}(\mu W_k, \sigma W_k^2) \sum_{i=1}^n tr_i \quad (63)$$

Only the animals suffering a mild or severe clinical infections are prescribed a recovery period ($rv[E]_{i,j}$). The period of recovery is dependent on the infection, and severity of, the animal is enduring as well as it's age. The recovery period is distributed by the uniform distribution.

$$rv[E]_{i,j} = \begin{cases} U(mri_{d,z}, mrxd_{d,z}) & \text{if } suc_{d,z} < ds[E]_{i,j} \leq mic_{d,z} \\ U(sri_{d,z}, srx_{d,z}) & \text{if } suc_{d,z} + mic_{d,z} < ds[E]_{i,j} \leq sec_{d,z} \end{cases} \quad (64)$$

Due to the lack of published data concerning the weight loss an infected animal would undergo, alternative methods had to be considered in order to estimate the value of weight lost ($VWL[E]_{i,j}$) other than binomially distributing a probable weight loss parameter. The average daily gain (ADG_k) of an animal in k was therefore considered. Animals suffering from a mild or severe clinical infection were assumed to have a daily feed intake of zero on the first day of infection and therefore no weight gain. The ADG of the animal increases arithmetically during its recovery period, determined with Equation 64, until fully recovered and where the ADG of the animal is once again stable. The weight lost as a result of infection is estimated in concurrence with the weight it would have gained if it was not infected less the weight it gained during infection. However, if the animal dies as a result of infection, the weight lost is estimated according to its weight at death by a normal distribution. The average market price according to an animal in k is considered for the estimation of $VWL[E]_{i,j}$ for both scenarios.

$$VWL[E]_{i,j} = \begin{cases} \left(ADG_k \times rv[E]_{i,j} - \frac{rv[E]_{i,j}(0+ADG_k)}{2} \right) \times \mu Price_k & \text{if } suc_{d,z} < ds[E]_{i,j} \leq mic_{d,z} + sev_{d,z} \\ \mathcal{N}(\mu W_k, \sigma W_k^2) \times \mu Price_k & \text{if } suc_{d,z} + mic_{d,z} + sev_{d,z} < ds[E]_{i,j} \leq 1 \end{cases} \quad (65)$$

The cost of feed consumed by a recovering animal ($CRF[E]_{i,j}$) is estimated accordingly. The total cost of feed consumed in one year is accounted for by considering the difference of $ExpFeed_i$ and $\sum_{j=1}^{CS} CRF[E]_{i,j}$. The cost for a feed type f consumed by a recovering animal is identified by equation 66.

$$CRF[E]_{i,j} = \frac{rv[E]_{i,j} \times \left(0 + \left(0 + (rv[E]_{i,j} - 1) \times \frac{adf_{f,k}}{rv[E]_{i,j}} \right) \right)}{2} \times feedcost_f \quad (66)$$

The cost of compensatory growth ($CCG[E]_{i,j}$) is estimated, once the animal has recovered. Compensatory growth is accounted for once the animal's ADG is stable. With a stable ADG it is possible to estimate the number of days the animal needs to feed in order to attain the weight it was before infection. The information is further translated into the cost for each day of compensatory growth.

$$CCG[E]_{i,j} = \frac{ADG_k \times rv[E]_{i,j} - \frac{rv[E]_{i,j} \times (0+ADG_k)}{2}}{ADG_k} \times feedcost_f \quad (67)$$

The cost of dipping ($ExpDip_{i,j}$) per animal only considers the cows in the breeding herd. The number of monthly dips a cow will receive is dependent of the dipping strategy l , see Table D.1. The cost of dipping a cow per year is estimated in concurrence with whether it will remain alive at the end of a year or is removed during the year. The cost of a single dip per animal (dc)

is estimated based on the assumption that one cow removes four litres of dip mixture.

$$ExpDip_{i,j} = \begin{cases} BC_{i,j} \times dc \times \sum_{m=1}^{12} \frac{dip_{l,m}}{MR_{i,j}} & \text{if } BC_{i,j} = 1 \\ BC_{i,j} \times dc \times \sum_{m=1} dip_{l,m} & \text{if } BC_{i,j} = 0 \end{cases} \quad (68)$$

4.4 Model simulation

4.4.1 Description of the typical farm simulated

The model is simulated for fifteen years based on the following description of a typical sour veld farm in the KwaZulu-Natal Midlands. Each simulation is iterated 100 times. Each iteration represents one breeding herd. The model excludes herds grazing on leased land and considers farms where nothing is owing on the land. Therefore the cost of grazing is not considered and area is not included.

The climate of the KwaZulu-Natal Midlands experience hot and wet summers with average daily temperatures ranging between 25°C to 30°C, winters a cooler and dryer. Average yearly rainfall is ± 800 mm. Refer to Figure A.1 for the geographical location of the KwaZulu-Natal Midlands. Beef herds are largely comprised of *Bos taurus* cross *Bos indicus* breeds and a fewer *Bos indicus* pure bred cattle. No beef producers farm pure bred *Bos taurus* cattle. Therefore, the inclusion of the *Bos taurus* and *Bos taurus* breeds in the simulation were ignored due to the lack of animals in the area of study and to avoid risk of bias occurring when determining default input parameters discussed in Section 4.5. Breeding cows are generally kept until the age of ten years. In turn, this allows a producer to receive eight breeding seasons from a cow.

Cows, weaners and calves are fed supplements during the year whilst grazing the veld. Supplement types including Rainfos P9, Macosca Brew, Bovine 50 and a the Accelerator creep feed were incorporated in the model. Rainfos P9 is fed to cows and weaners for four and a half months from mid-October to the end of February. Macosca Brew is fed to the cows for four months, starting at the beginning of March until the end of June. Bovine 50 is fed to the cows for three and a half months from the beginning of July until the mid-October. The creep feed accelerator is fed to calves and weaners. Calves will generally start consuming the supplement at the age of one month. The supplement is consumed up until the animal is no longer a weaner or has been sold. Weaners graze on Italian rye grass pastures during winter and spring. Data concerning the feeding scheme is discussed in Section 4.5.

Animals receiving an infection other than a subclinical infection are treated once by two different treatment types. The two treatment types are Foray 65 and Metacam.

4.4.2 Redefining dipping strategies for the typical farm

The dipping strategies adopted in the KwaZulu-Natal Midlands differ slightly in definition with those identified by Smith *et al.* (2000). Therefore, the following descriptions for each dipping strategy are

1. Intensive dipping: the application of acaricide in strict and rigorous intervals in an attempt to eradicate the tick vectors and therefore, the prevalence of *Babesia* parasites
2. Strategic dipping: the application of acaricide which attempts to control the tick vector population at a level which is conducive for the increase in *Babesia* prevalence, but not detrimental to the herd population or the health of an individual cow.

4.4.3 Simulation scenarios

To conduct a financial analysis of the two dipping strategies defined in Section 4.4.2, four different simulation scenarios were identified. The scenarios were identified in correspondence with the first four epidemiological situations identified by Norval *et al.* (1983) where the average of each situation was assumed. Each scenario is simulated for *Bos taurus* cross *Bos indicus* breeds. The four following scenarios simulated are

Scenario 1: 90% positive sera as per an endemically stable situation

Scenario 2: 70% positive sera as per a situation approaching endemic stability

Scenario 3: 40% positive sera as per an endemically unstable situations

Scenario 4: 10% positive sera as per a situation of minimal disease.

A fifth, disease free, simulated scenario is conducted. This scenario is included in order to provide production results of a healthy farm. The healthy farm is assumed to practice intensive dipping due to no presence of bovine babesiosis and according to the definition provided by point one in Section 4.4.2. Therefore, only the preventive costs are included in the simulation. Financial results of the healthy farm are compared with those of the intensive and strategic dipping programmes threatened by the prevalence of either *Babesia* parasite as per the scenarios listed above. Healthy farm financial results will provide an indication of the net cash flow achievable in a state of no disease, and therefore the revenue forgone as a result of disease is comparable with this situation. Results are presented in Section 5.4.

4.5 Data collection

Given the fundamental nature of exploratory research, it often relies on data collection techniques such as reviewing secondary data and conducting unstructured and semi-structured interviews. In the case of this study, published data reviewed in Section 3.4 and 3.5 were considered

when developing the model. However, the published data reviewed was not used in the model since much of the available literature is concerned with *Bos taurus* cattle and were not applicable to the region of study. No published literature exists concerning the production performance of animals in the KwaZulu-Natal Midlands either. It was therefore decided to consult experts in the area for valid input parameters and to use available farm records of production performance. The defined input parameters for the simulations are available in appendices B to J.

Since little published data concerning the production effects of bovine babesiosis and the severity of disease exists, semi-structured interviews with expert veterinarians in the area of study were conducted. The two veterinarians interviewed practise at the Mooi River Veterinary Clinic (MRVC) and both have nearly 30 years worth of experience in the KwaZulu-Natal Midlands. A third veterinarian from the Howick Veterinary Clinic was interviewed. However, results obtained from the interview were discarded since this veterinarian largely deals with dairy herds. During the interview with the veterinarians from MRVC, disease severity parameters and the recovery periods for either clinical infection of a *Babesia bigemina* and *Babesia bovis* infection were defined. Furthermore, the definition of the two dipping strategies in Section 4.4.2 were defined as well as the composition of each. General treatment practices were also identified. The cost of dipping and treatment per animal were calculated according to the recommendations of use and the average 2018 cost per unit as per Midlands Veterinary Wholesalers (MVW) prices (MVW, 2018). The discussed parameters are available in appendices B to E.

Feed parameters concerning *ADFI* for the various supplement feed types (f) for animals in age class category k were defined during a semi-structured interview with a technical advisor of De Heus Animal Nutrition. Feed cost calculations for the supplements were derived from the cost and weight per unit as per the average 2018 TWK Agri (Mooi River) prices (TWK Agri, 2018). Dry land pasture costs were estimated based on the Department of Agriculture, Forestry and Fisheries machinery cost guide (DAFF, 2018) with an adjusted fuel price as recommended by the Automobile Association of South Africa (AA, 2018). Seed, chemical and fertiliser costs were modelled based on TWK Agri costings (TWK Agri, 2018). Stocking rates of five weaners per hectare of pasture and a grazing period of 210 days were assumed as per Bartholomew and Louw (2005). Feed parameters and planting costs are available in Appendix F and G, respectively.

Data from monthly sales reports by AAM Livestock Agents and Auctioneers (AAM, 2018) were collected in order to define the relevant weight distributions for animals in either age class category. Monthly sales data from February 2017 to February 2018 were collected. Commercial and trade animals were identified; the latter were excluded from the summary. Weight parameters are available in Appendix H.

Parameters pertaining to the average daily gains of an animal in age class category k were collected through farm records. Clients of De Heus Nutrition who were feeding the Accelerator creep feed to calves and weaners being backgrounded on pastures were identified. Farmers in the KwaZulu-Natal Midlands generally do not weigh their breeding herd thus making it challenging to gather these data. A regional consultant who had access to these data was contacted and agreed to share. The average daily gains of a breeding cow was averaged over a year in order to account for periods of no growth during winter, while in-calf and calf-at-foot and periods of weight gains during spring, summer and while dry.

Input parameters coinciding with Table 4.1 including the cost of pregnancy testing are identified in Appendix I. Parameters were identified during the interview with the expert veterinarians

of MRVC. Furthermore, they were identified based on the assumption that herd management and health are held at a high level, as well as farm facilities being in excellent condition.

4.6 Economic impact and financial analysis

The impact assessment and financial analysis of the simulated results pertaining to the mutually exclusive dipping strategies for each scenario, as discussed in Section 4.4.3, for a *Babesia bigemina* and *Babesia bovis* infection follows a two part procedure. The first part considers the economic impact of bovine babesiosis in each simulated year for a stable breeding herd of size *CS*. The economic impact includes all discounted preventive and failure costs for either dipping strategy. For each scenario, the discounted preventive and failure costs of either dipping strategy are compared with another to identify which dipping strategy incurs greater discounted economic consequences.

The second part of the analysis follows an investment appraisal of either dipping strategy. A real interest rate (r) of 5.16% is used. The real interest rate is obtained with a nominal interest rate of 10% and an inflation rate of 4.6% (South African Reserve Bank, 2018). Only the cash flows directly related to the production of beef weaners are included in the appraisal. Cash outflows consist of all inputs used for production such as feed and pregnancy testing costs. Disease related resources such as preventive, treatment and recovery expenditures are also included. The costs incurred due to disease such as the value of dead animals and the value of weight lost in mild or severe clinical infections are not included in the appraisal since they are not inputs. These costs are considered as revenue forgone and are reflected in the decrease of cash inflows by means of fewer animals reaching the market. Cash inflows consist of the revenue received for the sale of oxen, heifers and cull cows. Financial indicators such as the net present value (*NPV*) and the internal rate of return (*IRR*) are used in the appraisal.

4.7 Sensitivity analysis

A sensitivity analysis is performed to test the effect of varying input parameters has on the output of the financial results. The analysis is conducted by fine tuning certain input parameters in a realistic manner as follows. The price received per kilogram of an animal in either age class category is decreased and increased by 10%, the cost per dipping per cow is decreased and increased by 20%, the cost per treatment per animal is decreased and increased by 10% and the conception rate is increased by 10 percentage points. The effect of weaning calves at an older or younger age is also tested. For this, the probability parameters of a cow being bullied in either the first, second or third month of bulling are adjusted. In order for calves to be weaned at an older age, the probability of a cow being bullied in the first month is increased by 25 percentage points and the probability of being bullied in the second and third month are decreased by 20 and 5 percentage points, respectively. Increasing the probability of cows being bullied in the first month to 85% would allow for 85% of the available calves at weaning to be weaned at the age of seven months. In order to achieve the majority of calves to be weaned at a younger age of five months, the probability of a cow being bullied in the first and second month is decreased by 55 and 20 percentage points, respectively, whereas the probability of a cow being bullied in the third month is increased by 75

percentage points.

4.8 Conclusion

Chapter 4 is concerned with model development and the system it simulates. The theory of a typical farm is discussed and adopted in order for the fair comparison of simulation results. System assumptions which are incorporated within the model are identified during the development phase. The model consists of four components and are discussed in Section 4.3. The first component simulates the production of beef weaners with a stable breeding herd for the start of each simulated year. The second component simulates the cash inflows and outflows directly related to the production of beef weaners and the stable breeding herd. The infection of disease and the severity of an infection is simulated in the third component. In the fourth component, the preventive and failure costs are modelled. The sum of the preventive and failure costs per year are regarded as the economic impact. Disease related cash flows such as the treatment, preventive and recovery costs are included in the financial analysis. A reduced number of animals reaching the market as a result of acute deaths are regarded as revenue forgone and is reflected in the reduced cash inflow. Production and disease related cash flows comprise the financial analysis. Section 4.4 describes the typical farm of the KwaZulu-Natal Midlands which is simulated; redefines the dipping strategies that are typically adopted in the region; and presents the scenarios per dipping strategy per *Babesia* infection. Data collection methods and the data incorporated in the model as default input parameters are discussed in Section 4.5. The altering of parameters for the sensitivity analysis are discussed in Section 4.7.

Chapter 5

Results

5.1 Introduction

Chapter 4 introduced the development of the model and describes the respective components. It further discusses the characteristics of the typical farm of which various scenarios of *Babesia bigemina* or *Babesia bovis* prevalence are simulated in accordance with the identified dipping strategies. In this chapter the results of each scenario respective to the dipping strategy simulated 100 times over fifteen years are presented. Section 5.2 presents the results of the breeding herd composition, the physical production of oxen, heifers and cull cows sold, the number of replacement heifers retained or purchased. Disease incidence is included where the proportion of immune animals and those suffering a primary infection are discussed. The proportion of animals removed from the herd as a result of a disease induced acute death is also discussed. The economic impact and financial analysis for each dipping strategy per scenario are presented in Section 5.3. The financial effects of bovine babesiosis on the net cash flow for each dipping strategy per scenario of a *Babesia bigemina* or *Babesia bovis* infection are presented in Section 5.4. Discounted net cash flows are compared with the estimations of what could be achieved as a healthy farm. Sensitivity analysis results are presented in Section 5.5.

5.2 Herd composition and physical production

This section provides the results of the simulated scenarios of both dipping strategies for *Babesia bigemina* and *Babesia bovis* induced bovine babesiosis. Drawing attention to the composition of the herd and results of the physical production are important for the assessment of production losses. The various scenarios of disease prevalence within the different dipping strategies will have an effect on the production components within the model. The number breeding cows available at year end will have an effect on the number of replacement heifers retained, sold and purchased. Death of breeding cows will affect the number of weaners produced for sale despite the fixed input parameters. The number of weaners produced and sold will also be affected by death due to disease.

Results for each one of the 100 iterations are averaged for each simulated year. Results are discussed relative to the number of simulated cow-spaces ($CS \times 100$ iterations) at the start of each year. The calving and weaning rates are expressed as a percentage of the number of calves born and the number of calves weaned per the number of cows bulled in each iteration. All cows were assumed to have been covered by a bull. The required amount of replacement heifers for each year corresponds with the number of breeding cows removed from the herd in the same year and accounts for those which have reached the maximum number of breeding season. The replacement heifers retained or purchased in one year will enter the herd in the following. The mean number of breeding cows remaining at year end, calves born and weaned as well as oxen, heifers and cull cows sold are presented graphically. The standard deviation for each respective year in every simulation is graphically represented by error ribbons. In turn this section will aid in the discussion of the financial results.

5.2.1 Scenarios concerning a *Babesia bigemina* infection for intensive and strategic dipping

Scenario 1: Intensive dipping

The composition of the breeding herd illustrated in Figure 5.1 remains at an average of 81 breeding cows for each year end where a *Babesia bigemina* prevalence is held constant at 90%. Animals incurring a primary infection increases by 3.8% in the first four years. From the fourth year cows incurring a primary infection remains constant at an average of 7.9%, depicted by an average number of eight cows in Figure 5.1. The increase in primary infections in the first year to the fourth resulted in an increase of 0.1% to 0.3% of acute deaths. The stable primary infection rate from the fifth year onwards is comprised of a 0.3% average of acute deaths occurring. Primary infections within the breeding herd still occur due to naive replacement heifers entering the herd by replacing the cull cows. On average, 85.9% of the cull cows were immune.

All the breeding cows removed from the simulation subject to culling, natural deaths and disease mortality reasons were replaced by retained heifers. A 90% seroprevalence did not result in any purchased replacement heifers for any of the fifteen simulated years. Immune replacement heifers entering the breeding herd were on average 52% of the total replacement heifers. Primary infections in the breeding herd are attributed to the disparity in susceptible and immune heifers entering the herd. Heifers retained for replacement purposes made up 60% of the available heifers produced.

Mean results yield an average 82.6% calving rate for each year. In subsequent years an average of 2.2% less calves were weaned as a result of the mortality rate. No calves were lost due to acute deaths of a *Babesia bigemina* infection. The proportion of immune calves remained constant in each year where 27% of the total calves had seroconverted by the time of weaning. In subsequent years of calving, oxen and surplus heifers are sold. Average results indicate that 39 oxen and 16 heifers were sold in each year, illustrated in Figure 5.1.

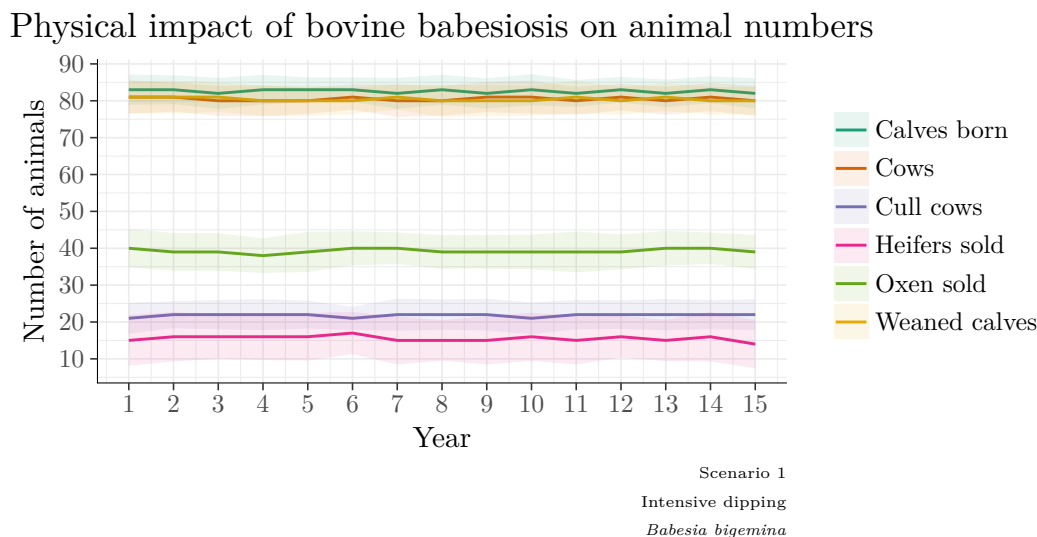


Figure 5.1: Composition of mean animal numbers in Scenario 1 of an intensive dipping strategy challenged with *Babesia bigemina*.

Scenario 1: Strategic dipping

Adopting a strategic dipping strategy from an intensive dipping strategy at a 90% seroprevalence of *Babesia bigemina* results in a similar breeding herd composition to that of the intensive dipping programme in Scenario 1. Figure 5.2 illustrates that 81 breeding cows remain in the herd at year end after the removal of animals for culling, natural deaths and disease mortality reasons. Mortality as a result of primary infections leading to acute deaths is responsible for an average of 0.1% in each year. Primary infections decrease from 7.9% to 4.5% in the first three years. An average primary infection rate of 4.2% in the breeding herds per year is incurred from the fourth year onwards. All remaining breeding cows have attained immunity at each year end, including all those that were removed subject to reasons of culling.

Replacement heifers entering the breeding herd averaged at 23.7% of the breeding herd for each year. An additional 4.3% of replacement heifers are retained to account for the breeding cows culled after weaning in the following year since they have reached their eighth breeding season. The average numbers of produced heifers exceeded the herd's replacement requirements for every year and therefore, no replacement heifers are purchased. Surplus heifers were sold and are depicted in Figure 5.2. An average of 77.7% of the retained replacement heifers entered the breeding herd having attained immunity in each year.

The annual calving rate is held constant at an average of 82.7%. In the following years of calving an average weaning rate of 80.4% of the breeding herd is achieved. However, in the first year weaning rates are the highest at 81.3% due to weaning having occurred in the first four months of the fifteen year strategic dipping simulation. The dams of these weaners would have calved in the previous year, thus before being challenged by an increasing *Babesia bigemina* infection. Furthermore this results in the lowest proportion of immune calves weaned. Only 36.9% of the calves had seroconverted by the time of weaning compared with the following fourteen year average of 47.8%. Oxen and heifers sold remain at constant rates of 54.9% relative to the breeding herd for

each year, of which mean results indicate 40 and 15 oxen and heifers per year, respectively.

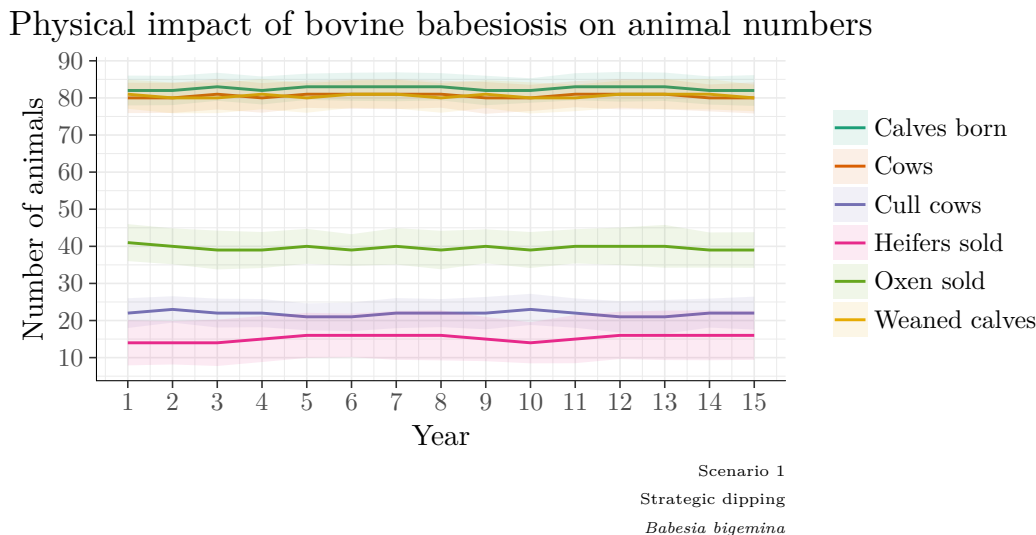


Figure 5.2: Composition of mean animal numbers in Scenario 1 of a strategic dipping strategy challenged with *Babesia bigemina*.

Scenario 2: Intensive dipping

Intensive dipping in Scenario 2 where a 70% seroprevalence of *Babesia bigemina* exists results in the breeding herd remaining constant at 80.6% of the simulated cow-spaces each year. Figure 5.3 depicts this proportion at an annual average of 81 breeding cows. An average primary infection rate of 8.4% within the herd incurs, followed by an average of 0.2% acute deaths. The year end immunity status of the herd is constant at a mean level of 58.3% from the fourth year onwards as a decrease transpires in the first to the third year from 63% to 59.9%. In the same years, the cull cows were composed of 71%, 70.5% and 68.7% immune animals. The decrease in herd immunity is explained by 67.8% of the cows culled in the fourth to the fifteenth year having seroconverted. Therefore, higher proportions of immune cattle were removed in the first three years where the percentage of immune replacement heifers is not sufficient to maintain the herd's immunity status. In each year, an average 30.4% of replacement heifers had acquired immunity.

The average number of breeding cows removed from the herd each year is less than the amount of heifers produced. Mean results indicate that the number of heifers retained for replacement is held constant with an average of 23.7% relative to the cow-spaces for each year of which an additional 4.3% are retained to account for the cull cows having calved for eight seasons.

The number of calves born is held steady at an average calving rate of 82.6% as depicted by the average number of calves born each year in Figure 5.3. Subsequent years experience a decrease of 2.2% of calves at weaning. The drop in calving rate to a weaning rate of 80.4% is due to natural mortalities since no *Babesia bigemina* induced acute deaths occur. Of the calves weaned, 11.9% of them had acquired immunity. A small proportion of primary infections occurring in the annual weaner cohorts are kept constant at 15.3% of the weaners in each year. The number of oxen and heifers sold during the year hold an annual average 40 and 15, respectively.

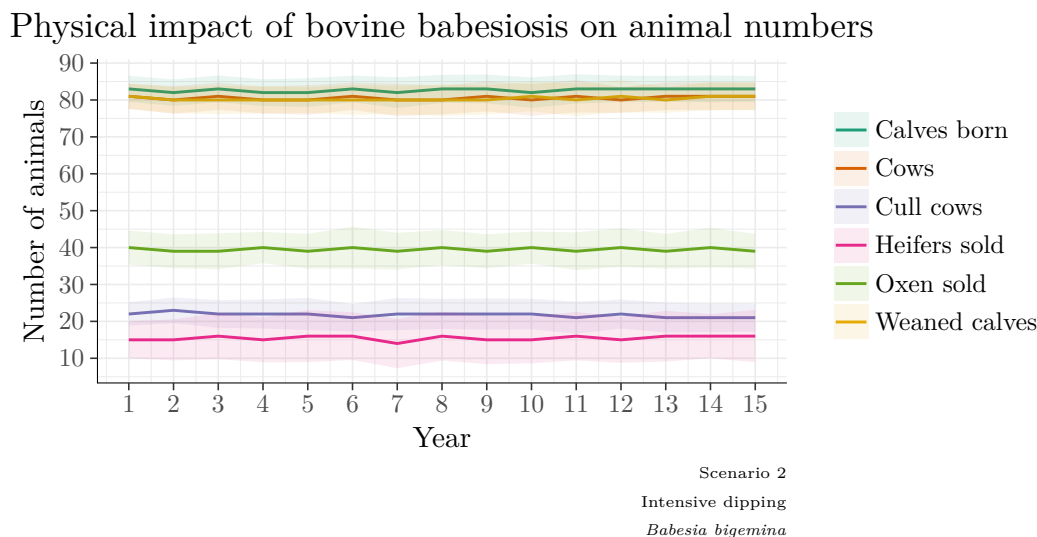


Figure 5.3: Composition of mean animal numbers in Scenario 2 of an intensive dipping strategy challenged with *Babesia bigemina*.

Scenario 2: Strategic dipping

A move from an intensive dipping programme to the strategic strategy with a *Babesia bigemina* seroprevalence of 70% prior to the change results in an increase of primary infections during the first year; 23.9% of the breeding cows receive a primary infection. From the second year and onwards, an annual mean of 4.3% of the herd incur a primary infection. Despite the increase in primary infections experienced during the first year, the average herd at year end is 80.4% of what it was at the beginning of the year. Figure 5.4 depicts the stable average number of breeding cows remaining at year end is 80 animals. However, the increase in primary infection during the first year results in the greatest percentage of acute deaths occurring during the fifteen year simulation at 0.7%. During the second to the fifteenth year, the number of acute deaths occurring is less where 0.1% of the breeding cows are lost. In the second year and onwards, all cull cows are immune.

All replacement heifers are retained heifers due to the breeding herd remaining at the year end averages as depicted in Figure 5.4. The average heifers produced for each year is 39.1% of the breeding herd of which 60.8% are retained for replacement. Cows which are culled for reasons of age are accounted for by the replacement heifers. The breeding herd's low rate of primary infections is aided by the high immunity status of the replacement heifers entering the herd in subsequent years, where by 77.7% of them had seroconverted.

The low percentage of breeding cows removed from the herd due to acute deaths has little effect on the calving rate. The breeding herd calved at an average of rate of 82.5% in each year, depicted by the mean number of 83 calves born per year in Figure 5.4. Of the calves born in the last quarter of the year, 97.3% of them are weaned at the end of the fourth month in the following year, illustrated by the mean number of 80 in Figure 5.4. At the average age of six months, the proportion of immune calves weaned from the second year and onwards, lies at 47.7%. However, in the first year only 34.7% of the calves had seroconverted before weaning. A lower proportion of immune calves at the time of weaning in the first year compared with the average immunity

status of weaned calves in the second to the fifteenth year is due to them having been born in the previous year of an intensive dipping strategy. The calf cohort in the first year were introduced to an increase in a *Babesia bigemina* challenge for only four months. The lower infection rate in the herd within the first year transpires to a lower proportion of calves receiving a primary infection in the first year. Despite the greater susceptibility of weaners in the first year, the number of oxen sold is 1.0% greater than the following fourteen year average where 39.2% of the cow-spaces were sold oxen. Heifers available in the first and second year are 1.0% less than the average available heifers in the third to fifteenth year. The mean number of heifers sold during the fifteen year simulation period ranged from 14 to 16.

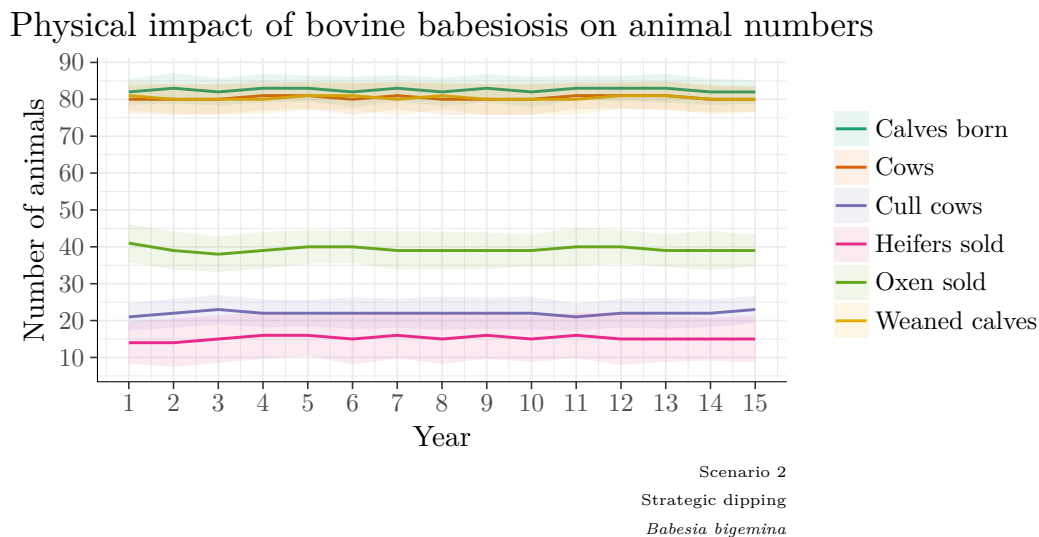


Figure 5.4: Composition of mean animal numbers in Scenario 2 of a strategic dipping strategy challenged with *Babesia bigemina*.

Scenario 3: Intensive dipping

An intensive dipping strategy adopted for a breeding herd with a *Babesia bigemina* seroprevalence of 40% maintains the number of cows at an average of 80.5% of the simulated cow-spaces at year end as presented in Figure 5.5. Primary infections in the breeding cows is held constant at an average of 6.1% and 0.2% acute deaths for each year. However, the immunity status of the herd decreases from 37.5% at the end of the first year to 32.7% at the end of the fifteenth year. The decrease in the level of herd immunity is attributed to the 41.5% of the cull cows being immune in the average year. The herd in turn is replaced by heifers of which 13.8% of them have attained immunity on average.

The constant number at which the breeding herd remains in each year end permits the produced heifers to be retained as replacements and in turn none are purchased. An average of 23.7% of the breeding herd are kept as replacement heifers. The 4.2% difference accounts for the cows culled for having reached the age culling. The average proportion of retained replacement heifers equates the required amount for each year, as well as the proportion of immune replacement heifers of which 13.8% of them have seroconverted.

Figure 5.5 shows the number of calves born is held constant for each year. An average of 82.6% calving rate is achieved. In subsequent years of calving, the average weaning rate is 80.4%. Furthermore, 6.4% of the calves which are weaned have received a primary infection and seroconverted. The low percentage of immune calves weaned transpires to the small proportion of heifers retained for replacement in the following years. Mean results of oxen sold remains stable for each year at an average number of 40 whereas heifer sales remain constant at an average of 16. The results of acute deaths occurring in weaners and retained heifers for each year accounts for an average of 0.2% of the produced oxen and heifers.

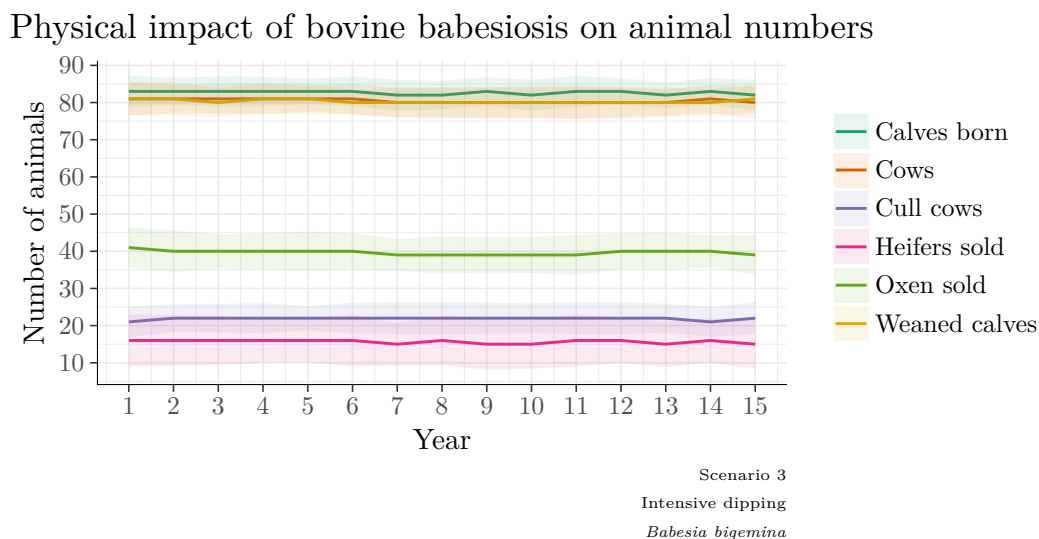


Figure 5.5: Composition of mean animal numbers in Scenario 3 of an intensive dipping strategy challenged with *Babesia bigemina*.

Scenario 3: Strategic dipping

Shifting from an intensive dipping strategy towards a strategic dipping programme where the seroprevalence of *Babesia bigemina* is at 40% at the start of the first year results in a high proportion of primary infections occurring. Mean results show 39.9% of the breeding cows suffer a primary infection with the change in dipping strategy, of which 1.3% died of an acute death. The herd's immunity status at the end of the first year holds at 89.3% of the remaining cattle after culling, natural mortality and disease induced mortalities have occurred. The second year of primary infections incurred result in a decrease of 25.7% in which 99.9% of the breeding cows have seroconverted by year end. From the third year and onwards, the primary infections the breeding herd incurs results in an average of 4.2%. Despite the increase in primary infections in the first year and the highest percentage of acute death occurring, the breeding herd at year end holds at 79.8% of simulated cow-spaces, Figure 5.6 illustrates that an average number of 80 breeding cows remain at the end of the first year. Following year ends see that a mean number of 81 breeding cows remain. All cull cows have attained immunity from the second year onwards.

A steady year end herd remaining at an average 80.5% of the simulated cow-spaces results in no replacement heifers having been purchased. The average proportion of retained replacement heifers, relative to the breeding herd, corresponds with the required heifers at an average of 23.9%

for each year. The outcome of adopting the strategic dipping programme allows for 78.1% of the retained replacement heifers to acquire an immunity from the second to the fifteenth year in comparison with 68.9% of immune replacement heifers retained in the first year.

The proportion of calves born were not affected by the increase in primary infections of the breeding herd. Figure 5.6 illustrates that the average number of calves born is held at an average of 83, with an annual calving rate of 82.6%. Results concerning the weaning rate in the first year is 2.0% greater than the second to fifteenth year average of 80.2%. A greater weaning rate in the first year is attributed to a greater number of available breeding cows present which would have calved the year before during an intensive dipping strategy. The seroprevalence of *Babesia bigemina* in the first year calf cohort at the time of weaning is 27.9%, whereas from the second year an average of 47.7% of the calves had received a primary infection and seroconverted by the time of weaning. The mean number of oxen sold in each year remains constant at an average of 40. In each year, 15 heifers are sold. The losses due to disease induced acute deaths are greatest in the first and second year where 1.4% and 1.0% of weaners and retained heifers are lost, respectively. An average of 0.8% of weaners and retained heifers subject to acute deaths are lost each year between the third and fifteenth years.

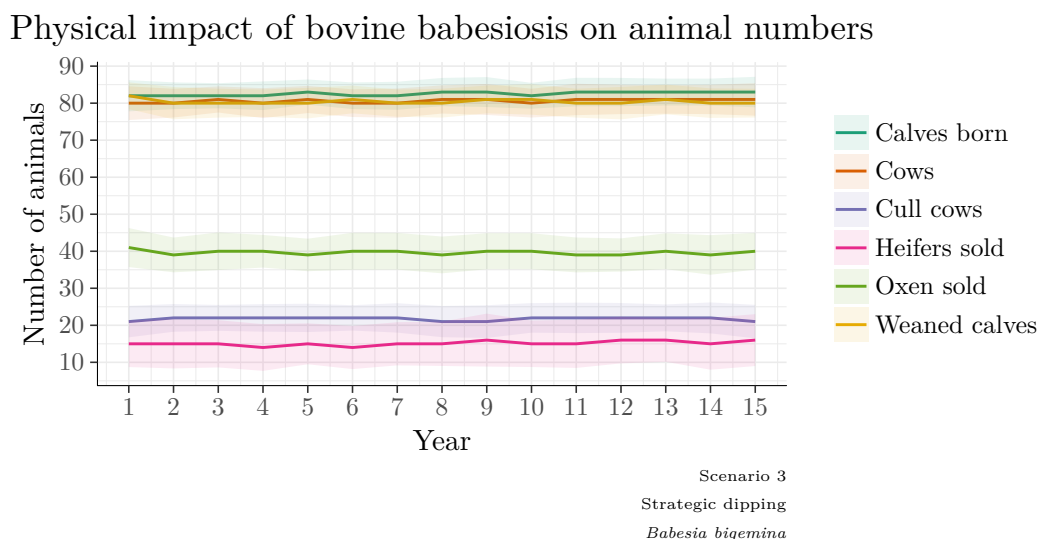


Figure 5.6: Composition of mean animal numbers in Scenario 3 of a strategic dipping strategy challenged with *Babesia bigemina*.

Scenario 4: Intensive dipping

The year end outcomes of the breeding herd remain constant in a situation of minimal disease with a 10% *Babesia bigemina* positive sera. Figure 5.7 delineates the mean number of breeding cows remaining at year end for each respective year, where an average of 81 animals exists. Primary infection within the breeding herd are minimal at an average of 1.8% occurring throughout the simulated years. As a result, 2.8% of the infected cows died from an acute death in each year. Of the remaining animals in the herd, 11.3% of them are immune. Cull cows are comprised of an average 11.3% immune animals per year.

Replacement heifers required in each year is held at a constant mean of 23.5% of the breeding herd of which the available heifers surpassed the requirements, therefore all replacement heifers were retained and none were purchased. A low proportion of 3.8% of the replacement heifers enter the breeding herd as immune animals ensures the minimal state of disease.

Results concerning the calving rate for the first year through to fifteenth remains constant where an average of 82.9% is achieved. The weaning rate in following years of calving drops by a mean of 2.3%, per year. Figure 5.7 depicts mean number of calves weaned in each year at 81. Of those calves which are weaned in each year, an average of 1.4% of them had received a primary infection and seroconverted; none were lost as a result of acute deaths. Acute deaths incurred in oxen and heifer cohorts in respective years held at an average of 0.1%. Furthermore, an average number of 40 and 16 of the breeding herd in each year are represented as oxen and heifer sales.

Physical impact of bovine babesiosis on animal numbers

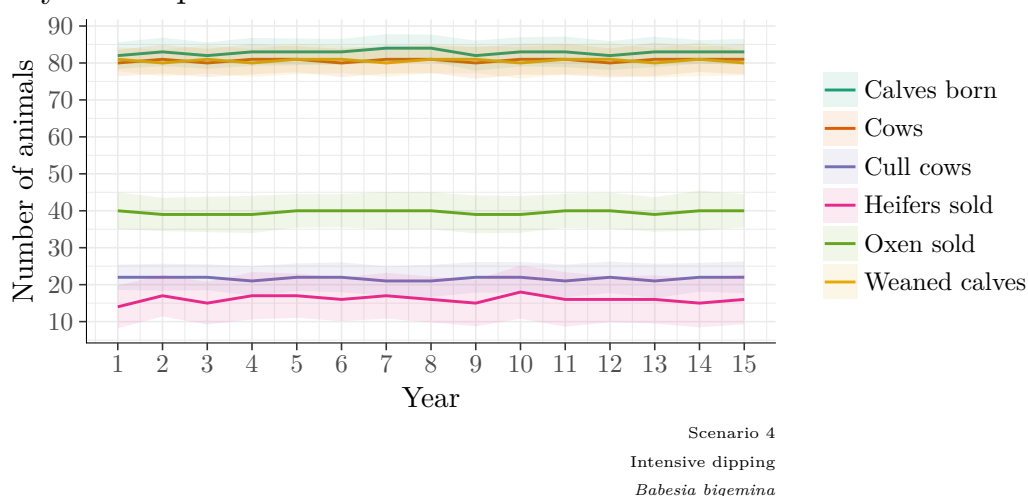


Figure 5.7: Composition of mean animal numbers in Scenario 4 of an intensive dipping strategy challenged with *Babesia bigemina*.

Scenario 4: Strategic dipping

Shifting from an intensive dipping strategy towards a strategic dipping programme in a situation of minimal disease results in an a high proportion of primary infections occurring during the first two years. Mean results indicate that 22.5% of the breeding cows experience a primary infection in the first year. In the second year the proportion of cattle receiving a primary infection increases to 41.3%. Resultantly, the proportion of remaining cattle in the first year consists of 38.1% immune cows. In the following year 87.2% of the remaining cattle have seroconverted. The breeding herd is subject to a lesser primary infection rate of 14.5% in the third year, by which all remaining cows have acquired immunity. Thereafter, primary infections incurred in the subsequent 11 years is held at an average of 4.3%. Despite the rise in primary infections occurring towards the spike in the second year, the breeding herd remains constant at a mean of 82 animals for each year, illustrated in Figure 5.8. Acute deaths following an infection is greatest in the second year where of 1.0% of the breeding cows is realised.

Primary infections in the breeding herd continued to increase in the second year due to the 30.4% of replacement heifers retained having seroconverted in the first year. The proportion of immune replacement heifers increases from the second year towards a 77.6% rate of stability that is achieved in the third year onwards. All replacement heifer requirements are met by retained heifers and none were purchased.

The number of calves born in each year remained stable. An average yearly calving rate of 82.4% is achieved. Weaning rates in following years also maintained consistency where a yearly 80.1% average realised. An increase in the immunity status of weaned calves is further achieved where 10.5% of the weaned calves in the first year had seroconverted, augmenting towards a stable rate of 47.3% from the fourth year onwards. No calves had fallen victim to disease induced acute deaths. However, the sum of weaners and retained heifers cohorts suffered an average 0.7% acute deaths for each year. Oxen and heifers sold were consistent from the first year onwards yielding a mean of 40 and 15, respectively.

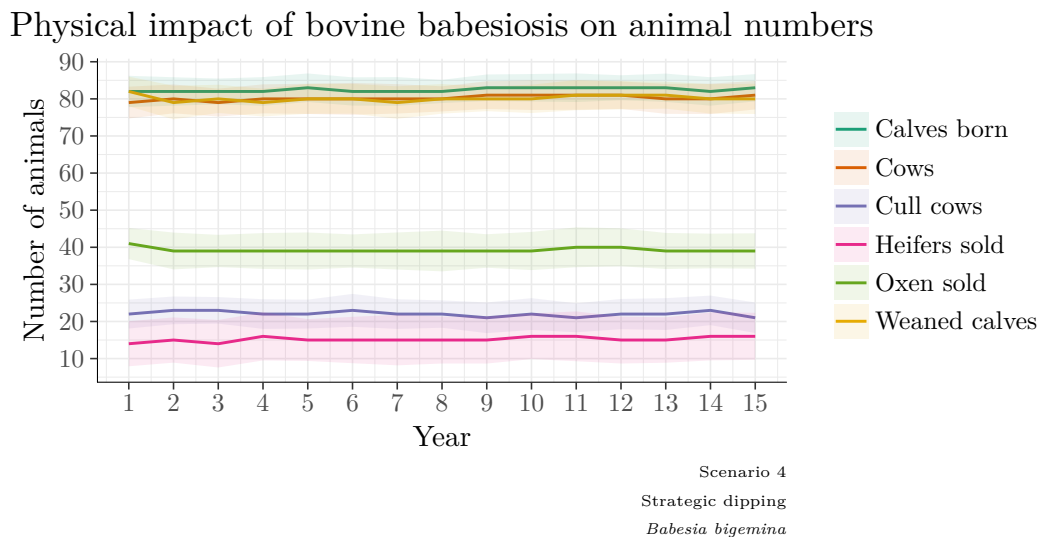


Figure 5.8: Composition of mean animal numbers in Scenario 4 of a strategic dipping strategy challenged with *Babesia bigemina*.

5.2.2 Scenarios concerning a *Babesia bovis* infection for intensive and strategic dipping

Scenario 1: Intensive dipping

A breeding herd of which 90% of the cows show *Babesia bovis* positive sera in the first year results in a decline of the year end breeding cow numbers during the fifteen year simulation when intensively dipped. Figure 5.9 illustrates that the mean number of remaining cows in the herd at year end decreases from 78 in the first year to 72 in the fifteenth year. Along with an annual decrease in herd numbers at year end, the proportion of immune cattle remaining at year end follows suite. From the first year to the sixth, the proportion of remaining resistant cattle decreases from 95.2% to 84.1%. The first year of cull cows consisted of 89.9% immune animals

and decreased to 75% in the sixth year. On average the replacement heifers entering the herd in subsequent years are 30.6% immune. Primary infections increase in the first six years from 4.2% to 13.3% of the breeding cows. Resultantly, an increasing rate of acute deaths occur from 2.5% in the first year to 8% in the sixth. This is followed by a yearly average of 14.1% primary infections and 8.4% acute deaths from the seventh to the fifteenth year. A high proportion of immune cull cows removed, replaced by a low proportion of resistant replacement heifers coupled with increased primary infections results in decreasing herd numbers at year end with a lower immunity status.

Mean simulation results show that on average the proportion of replacement heifers retained are greater than those purchased during the simulated years. Yearly replacement heifer requirements hold at an average of 30.7% of the breeding herd of which 91% are retained heifers and 9% are purchased.

The calving rate is held at its highest in the first year at a mean value of 80.4%, thereafter declining. Figure 5.9 illustrates that the calving rate in the second year realising an average of 77.8% decreases towards 75.6% in the fifteenth year. Subsequently, the weaning rate in the second year is held at its highest with a mean value of 77.2% and follows the decreasing trend of the calving rate. The weaning rate drops by 4.8% in the second year to the fifteenth year. At the time of weaning the yearly average of immune calves is 26.4% of all calves weaned. Calves subject to disease induced acute deaths realised a yearly mean of 1.3% of calves born. Almost a tenth of heifers and oxen weaned including heifers retained for replacement suffered disease induced acute deaths where a yearly average 8% is held. Mean results show that yearly heifer sales were still achieved, however a very low mean number of three occurred in the average year. Oxen sales remained constant at a yearly average of 33 animals.

Physical impact of bovine babesiosis on animal numbers

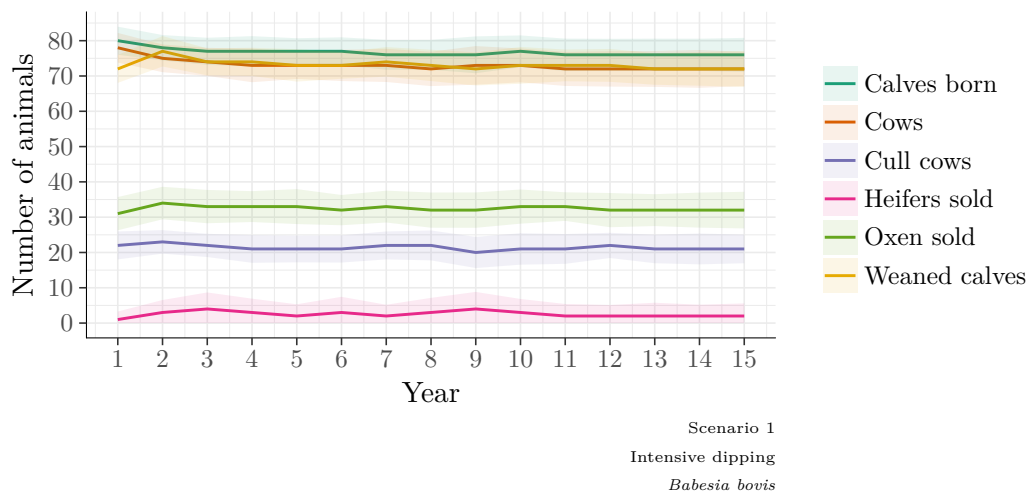


Figure 5.9: Composition of mean animal numbers in Scenario 1 of an intensive dipping strategy challenged with *Babesia bovis*.

Scenario 1: Strategic dipping

A change in dipping strategy from an intensive to a strategic dipping programme in the first year maintains 99.9% of the remaining year end cattle with immunity. Figure 5.10 delineates that the breeding herd at year end remains constant at an average of 74.5% of the simulated cow-spaces in each year. The proportion of immune cows culled are on average 89.6% of the total number of culled cows. The average primary infections incurred in the breeding herd for each year holds at an average of 10.3% of which transpires to 6.2% acute deaths occurring.

The replacement heifers entering the herd in subsequent years consist of 56.2% immune animals. However, the variation in the proportion of immune replacement heifers is indicated by standard deviations ranging from 6.4 to 8.6. A variation in the immunity of replacement heifers is incurred for the simulated years in which the immunity of a purchased replacement heifer is unknown, and therefore determined stochastically. Resultantly, the primary infections of cattle in the breeding herd vary. The average proportion of heifers retained for replacement are greater than those which are purchased in order to meet the consistent 29.5% of the breeding herd required in the average year.

The proportion of calves born each year realise an annual average calving rate of 77.8%, as seen in Figure 5.10 illustrating the mean number of 78. The weaning rate decreases by 2.5% from the first year to the third until it stabilises at 73.6%. The proportion of immune calves at the time of weaning increases from 35.7% to an average of 46% from the second year onwards. Mean results show that a yearly average of 2.3% of calves born were subject to acute deaths following a primary infection and combined average 9.8% for weaners and retained heifers. Resultantly, 86% of the oxen weaned in the current year of weaning were sold in the current and 10% of heifers were sold in following years, transpiring to mean number of 32 and four per year, respectively.

Physical impact of bovine babesiosis on animal numbers

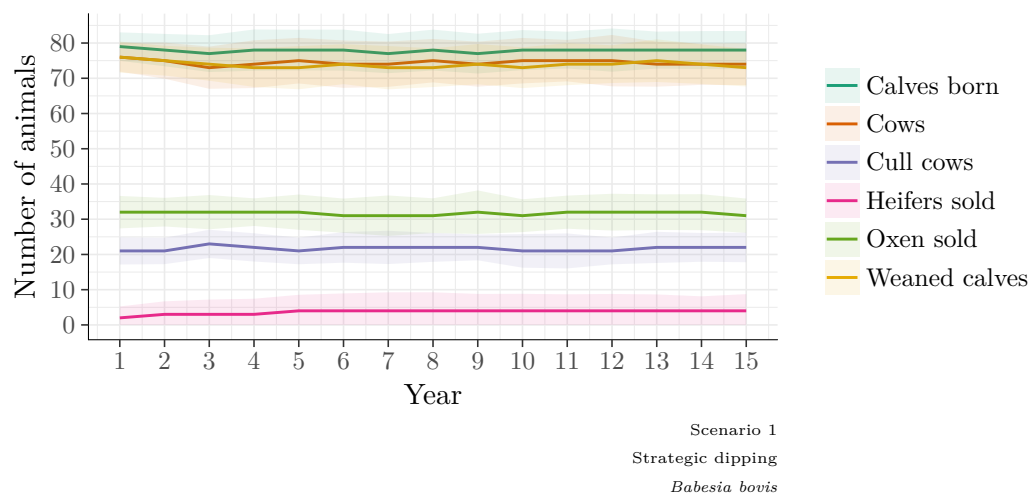


Figure 5.10: Composition of mean animal numbers in Scenario 1 of a strategic dipping strategy challenged with *Babesia bovis*.

Scenario 2: Intensive dipping

An intensive dipping strategy applied to the breeding herd with 70% positive *Babesia bovis* sera results in a decrease of cattle numbers until stability is achieved from the sixth year, as seen in Figure 5.11 depicting the mean year end numbers. The average number of cattle remaining at the end of the first year hold at 77 animals. The number of cattle in the following years decreases towards a mean of 74 breeding cows by the end of the fifth year. From the sixth year and onwards mean results show that 26.8% of the breeding cows are removed from the herd each year. The percentage of animals removed includes an average 7.5% of cows having died from an acute death which followed a primary infection, the balance are cull cows. Breeding cows receiving a primary infection held at a mean 6.2% in the first year increasing towards 11.6% in the fifth year. Thereafter, primary infections is held stable at a mean of 12.6% of the breeding cows. Cows which are culled in the first year consist of 70.7% immune cattle and decreases towards 54.1% in the seventh year. The large proportion of immune cows removed from the herd in the first seven years are replaced by the replacement in subsequent years. However, an annual average of 20.8% of these heifers are immune. Therefore, contributing to the decreasing trend in herd immunity and an increase in primary infections experienced in the first five to seven years.

Physical impact of bovine babesiosis on animal numbers

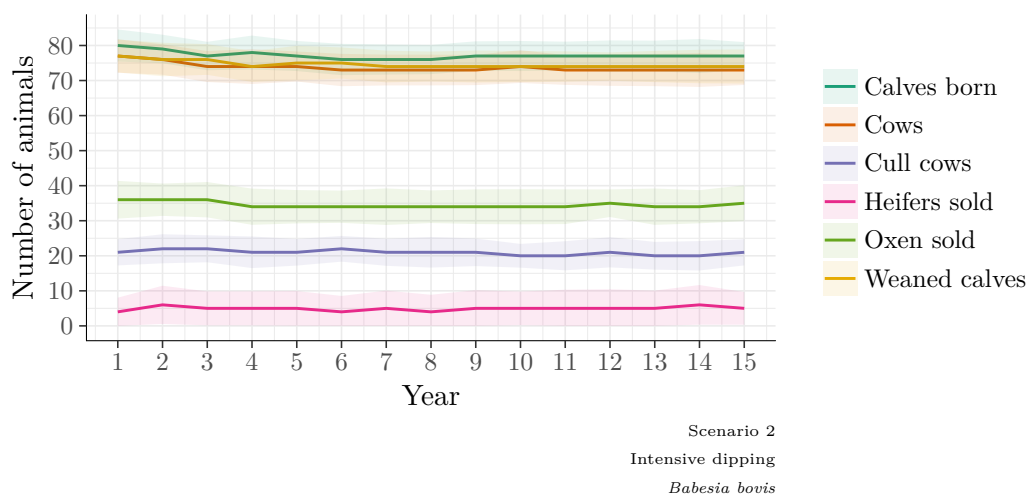


Figure 5.11: Composition of mean animal numbers in Scenario 2 of an intensive dipping strategy challenged with *Babesia bovis*.

Mean results indicate that in each year the available heifers produced surpassed the replacement heifers requirements. However, as the model accounts for variation within the 100 simulations, a yearly average of 95.7% of the required heifers were comprised of retained heifers and the difference are purchased. An intensive dipping programme in turn results in a low proportion of replacements acquiring immunity, as previously highlighted.

The mean calving rate for the first and second year holds at 79.3%, thereafter the average is 76.8% ranging from 76.1% to 77.5% from the third to the fifteenth year, as seen by the mean number of calves born in Figure 5.11. The weaning rate decreases from 76.6% in the first year to 76.1% in the third. From the fourth year the average weaning rate is 74%. By the time of weaning, an annual average 14.1% of calves had acquired immunity. A stable calving rate reflects a steady

proportion of oxen sold in each year. Of the oxen weaned 92.4% were sold in the current year, a yearly mean number of 34. Oxen lost are attributed to an average 6.2% subjected to disease induced acute deaths and the difference to natural mortalities. Heifer sales remain low but stable for each year where 13.3% of weaned heifers were sold in subsequent years, a yearly mean of five. Acute deaths incurred in weaned and retained heifers were stable at 5.9% and 2.6% per year.

Scenario 2: Strategic dipping

Mean results show that the breeding herd composition at the end of the first year is lowest where a shift in intensive dipping towards strategic dipping with a 70% *Babesia bovis* seroprevalence has occurred. Figure 5.12 illustrates that the mean number of breeding cows stands at 66.7% of herd capacity. During the year 24.1% of the cattle suffered a primary infection further resulting in 14.4% of the cows dying of an acute death. However, 99.1% of the remaining cows had acquired immunity. The second year holds an average of 70.3% of cattle remaining at year end where during the year 18.8% of the cows incurred a primary infection. Resultantly, 11.3% of the herd was lost to acute deaths. From the third to the fifteenth year, the proportion of remaining cattle at year end steadily inclines from 73.2% to 76.1% while primary infections decline from 13.2% to an average of 8.9% from the eighth year onwards. Immune animals present at year end consist of 99.9% of the cattle.

The greater requirement of replacement heifers corresponding with the lowest proportion of the breeding herd seen by the end of the first year is not met by the total heifers available. The replacement heifers entering the herd in the second year consists of 82.1% retained heifers and 17.9% purchase replacements. The proportion of purchased replacement heifers decreases towards the sixth year where mean results show that 2.1% are purchased. A greater variation in the proportion of immune heifers entering the herd exists due to the unknown immunity status of the purchased heifers. The variation in immune replacement heifers is greatest in the first four years corresponding with the greatest proportion of purchased heifers; standard deviations ranging between 8.3 and 9.2 is achieved. In turn, an increasing proportion of retained heifers make up the total replacement heifers. From the fifth to the fifteenth year, 79.7% of the heifers produced for replacement purposes have acquired immunity.

The number of calves born is affected by the change in dipping strategy. The calving rate in the first year is at the lowest compared with the following fifteen years. In the first year the average calving rate is held at 71.6%, 74.2% in the second and 76.7% in the third year. From the fourth to the fifteenth year the calving rate steadily inclines towards 79.1%. The weaning rate corresponds with the increasing calving rate from the second year onwards where an average of 4.1% of calves born either die of natural or acute deaths per year. However, the highest weaning rate of 77.7% occurs in the first year due to the calves having been born in the previous year where intensive dipping was still practised. Resultantly, the proportion of immune calves at the time of weaning in the first year is at its lowest where 33.1% of them had seroconverted. In subsequent years the proportion of immune calves present at the time of weaning increased towards an average of 46.4% from the sixth to the fifteenth year. With less than half the calves acquiring immunity by the time of weaning, oxen and heifers lost subject to acute deaths resulted in an average of 12.2% per year. The mean number of oxen sold in the first year was 32 animals. A drop of 2.7% is experienced from the first to the second year due to the calving shock in the previous. However, from the third year onwards the oxen sales relative to the simulated cow-spaces steadily increase

towards 32.5% in the fifteenth year. Due to the higher demand of required replacement heifers, mean results indicate that less than 1.0% of heifers were sold in the first year, but the decreasing herd requirements allowed an increase in heifer sales over the simulated years. An increase from 1.7% to 4.6% of heifers in the second to the fifteenth year relative to the cow-spaces are sold.

Physical impact of bovine babesiosis on animal numbers

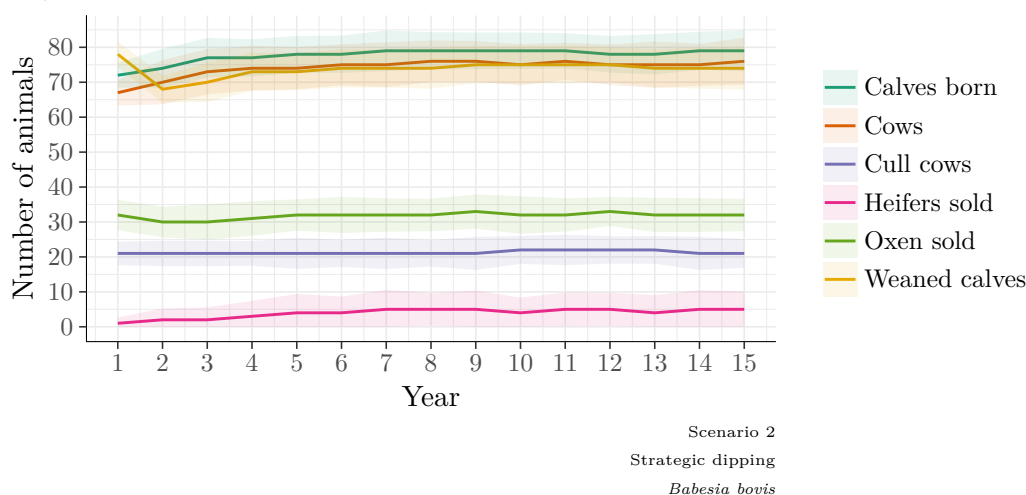


Figure 5.12: Composition of mean animal numbers in Scenario 2 of a strategic dipping strategy challenged with *Babesia bovis*.

Scenario 3: Intensive dipping

An intensive dipping programme applied in a breeding herd where a *Babesia bovis* seroprevalence of 40% is present in the first year yields results less severe than the former two intensive strategies. However, mean results show that over fifteen years the percentage of cattle remaining at year end follows a decreasing trend. Figure 5.13 delineates the mean number of breeding cows at year end decreases from 77 animals to 75 from the first to the fifteenth year. By the end of the fifteenth year, the number of remaining cattle in the herd has decreased by 1.6% on average. The proportion of immune cattle decreases from 44.8% to 27.8% from the end of the first year to the end of the seventh. During this time 41.1% of the cull cows in the first year are immune. In following years the proportion of immune cull cows decreases to 30.7% in the seventh year. The high proportion of immune cull cows removed each year coupled with an average 9.9% of the replacement heifers of the total required having seroconverted leads to an overall less immune herd. The decrease in overall herd immunity in turn results in a greater number of primary infections occurring each year. Primary infections increase from 5.9% in the first year to 7.4% in the fifteenth. The increasing primary infections occurring in the breeding cows as it follows a decreasing trend in immunity results in a greater proportion of acute deaths. Acute deaths increase from 3.6% to 4.6% over the fifteen year simulated period. Thus, the decrease in overall herd immunity due to a high proportion of immune cows being culled replaced by a lower proportion of immune replacement heifers contributes towards the fewer cattle remaining at year end.

Mean results show that available heifers exceed replacement requirements where a breeding herd remains above 75% of capacity at year end. Replacement requirements remain steady at

an average 27.2% of the breeding herd. Replacement heifers entering the herd in following years consists of 99% retained heifers and 1.0% purchases according to annual averages. Despite the available heifers surpassing the replacement requirements in each year, the purchasing of heifers are due to the variation in results between simulations. Available heifers show results where standard deviations ranging from 4.4 and 5.3 deviate from the yearly means.

The calving rates remain steady in each year where the mean results range between 78.6% and 80% between the first and the fifteenth year. The number of calves weaned in subsequent years of birth also remain stable where an average weaning rate of 76.8% is achieved per year. The intensive dipping programme in the breeding herd realises a low proportion of calves having acquired immunity where an average of 6.1% per year have seroconverted by the time of weaning. A low percentage of weaners succumbed to disease induced acute deaths where 2.8% occurred each year. The percentage of heifers retained for replacement purposes subject to acute deaths is also low where an annual average of 1.3% occurs. Oxen and heifer sales are consistent for each year where 37.1% and 8.9% of the bulled cows were sold in each year, transpiring to mean numbers of 37 and nine for heifers, illustrated in Figure 5.13.

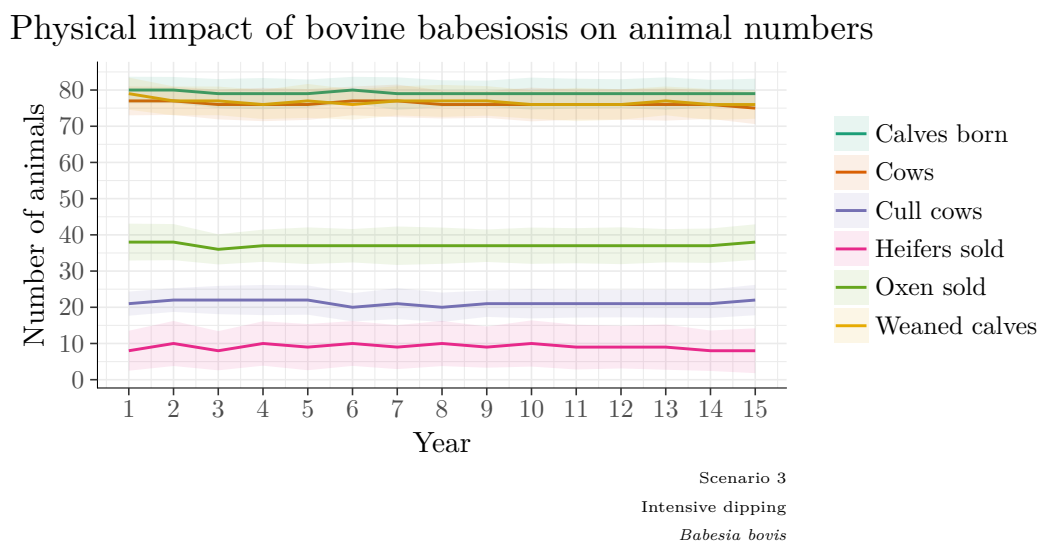


Figure 5.13: Composition of mean animal numbers in Scenario 3 of an intensive dipping strategy challenged with *Babesia bovis*.

Scenario 3: Strategic dipping

A change from an intensive to a strategic dipping programme for a breeding herd with 40% positive *Babesia bovis* sera leads towards adverse effects in the first year. In a situation where approximately 60% of the herd consists of naive cattle, the strategic dipping allows for an increase in primary infections to occur. Mean results indicate that 40% of the cattle received a primary infection. Resultantly, the severity of a *Babesia bovis* infection caused 24.1% of the cows to succumb to acute deaths leaving the herd at 56.9% of the simulated cow-spaces, a mean number of 57 breeding cows as illustrated in Figure 5.14. However, 84.4% of the remaining cattle had acquired immunity. Following years experience a decline in primary infections, and therefore fewer acute deaths. The percentage of the herd remaining at the end of the second year holds at a mean of 62%

increasing towards 75.9% in the fifteenth year. All remaining cows from the third year onwards are immune. The percentage of primary infections decreases from 32.6% to 10.6% in the second to the eighth year. Primary infections stabilise at an average of 9.7% in the breeding cows from the ninth to the fifteenth year.

The high proportion of cattle removed from the breeding herd requires for the purchase of replacement heifers. Available heifers for retention in the first year consisted of 70.1% of the replacement requirements, the balance were purchased. With an increasing number of cattle remaining in each year, the number of purchased heifers decreased in accordance from 29.9% in the second year to 9.9% in the eighth. The proportion of purchased heifers is greatest in the third year with 69.9% of the replacement consisting of retained heifers, since these animals were born in the first year of the strategic dipping programme. The proportion of retained heifers for replacement steadily increased from 79.1% to 92.1% of the total required replacements from the fourth to the fifteenth year. Variations in the simulation results exist, however, mean results indicate that the number of retained heifers is greater than the purchased replacement heifers. Therefore, the percentage of immune replacement heifers varies as a result of simulated data collected and is identified by the standard deviations ranging between seven and 10.1.

Physical impact of bovine babesiosis on animal numbers

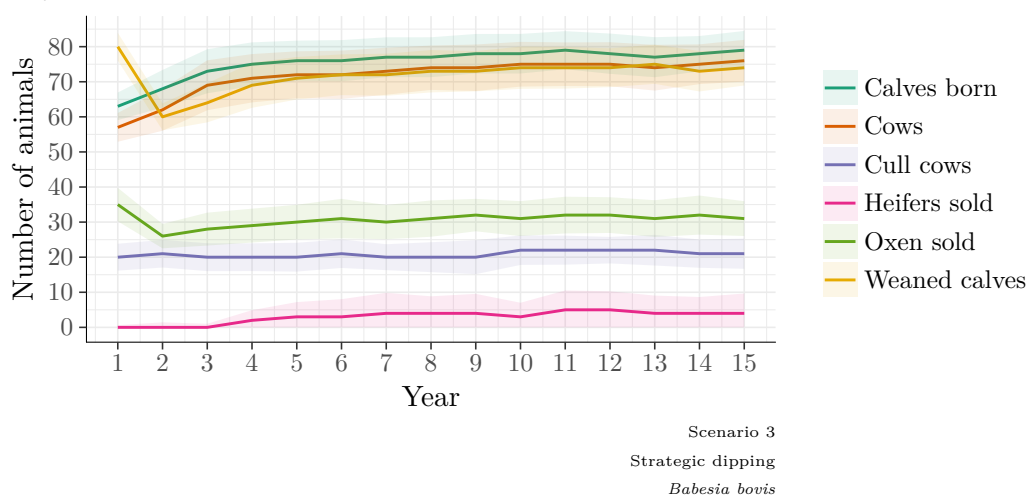


Figure 5.14: Composition of mean animal numbers in Scenario 3 of a strategic dipping strategy challenged with *Babesia bovis*.

The calving rate in the first year is at its lowest of 63.3%, in accordance with the number of cows remaining at the end of the respective year. Figure 5.14 delineates the number of calves born increasing from the first year onwards. A rapid increase of 11.7% in the calving rate is seen during the first four years where 75% is achieved. In the fifth year, the calving rate steadily inclines from 76.1% to 78.8% during the following ten years. The greatest weaning rate of 79.6% is achieved in the first year following an intensive dipping strategy of which the calves were born in the previous year. Calves weaned in the second year realises the lowest weaning rate of 60%, following the low calving rate in the previous year. The weaning rate in the third year increases by 3.9%. A further 7.3% increase is achieved from the third to the fifth year. From the sixth year to the fifteenth the weaning rate increases less rapidly from 72% to 73.6%. The first year of calves hold the lowest proportion of immune calves at the time of weaning where 27% is achieved. In the second year

the proportion of immune calves weaned consists of 42.8% of the group. From the third year onwards a steady number of immune calves are weaned where an average 46.4% of the group have seroconverted per year. Weaners in the first year of the simulation incur the greatest proportion of primary infection at a 34.4% as a result of a greater proportion of naive animals due to the intensive dipping programme implemented the year before. Primary infections occurring in the second to the fifteenth remains consistent at an annual average of 30.5% per year. Oxen sales were consequentially greatest in the first year where an average number 35 animals are sold. Following the low weaning rate in the second year, the mean number oxen sales of 26 animals is achieved. The third and fourth year experience an increase of 2.0% and 1.4% of oxen sales. In the fifth to fifteenth year, the mean number of oxen sales is steady, fluctuating between 31 and 32. Heifer sales remain below 1% for the first three years until, delineated by a mean of zero in Figure 5.14 increasing to 1.7% in the fourth year. Heifer sales remain steady in the following years ranging between a mean of three and five animals.

Scenario 4: Intensive dipping

Intensive dipping applied to a breeding herd where a state of minimal disease, 10% positive sera, exists results in the number of animals at year end remaining stable in each year of the fifteen year simulation period. Figure 5.15 illustrates a herd remains at an annual average of 80 breeding cows for each year end. The proportion of immune breeding cows in a herd steadily decreases from 10.9% of the remaining animals at the end of the first year to 6.1% by the end of the eighth year. From the ninth year onwards the mean immune remaining animals holds at 6.1%. However, the primary infections incurred remain constant at an average of 1.9% breeding cows per year. Resultantly, 1.5% of the cows die of an acute infection per year. The decreasing proportion of immune breeding cows is attributed to the high proportion of immune cull cows in the first five years which are replaced by a low proportion of immune heifers in subsequent years. The first year of cull cows consisted of 10.2% immune cattle. The proportion decreased to 7.7% in the fifth year. Replacement heifers entering the herd consisted of 2.6% immune animals per year.

Replacement heifer requirements are consistently met by the number of available heifers. An annual mean of 24.5% of the breeding herd is the replacement requirement. An additional annual 4.0% is retained to account for the cows culled for age reasons which are still included in the year end breeding herd count.

The calving rate is stable for the fifteen year simulation period. Figure 5.15 illustrates the mean results concerning the number of calves born is 82 where an average annual calving rate of 81.9% is achieved. Subsequent years show the results of the weaning rate at a constant percentage too where 79.5% is achieved. The proportion of immune calves at the time of weaning is constant at an annual average of 1.3% of the yearly calf cohorts. During the year, mean results indicate that an additional 1.2% of the weaners acquire immunity after weaning per year. Mean oxen and heifer sale remained constant in the simulated period where 39 and 14 are sold as oxen and heifers, respectively.

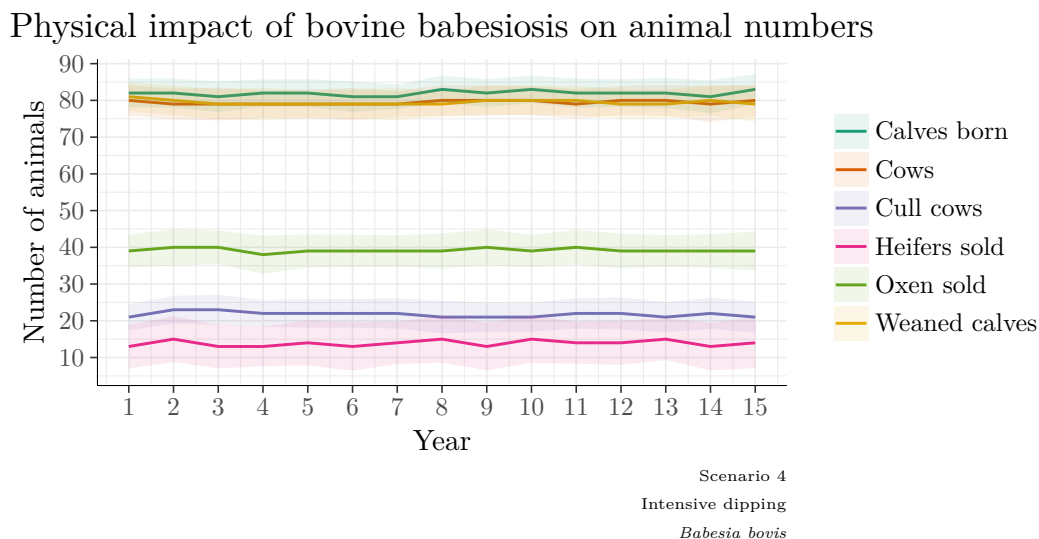


Figure 5.15: Composition of mean animal numbers in Scenario 4 of an intensive dipping strategy challenged with *Babesia bovis*.

Scenario 4: Strategic dipping

Herds faced with a minimal *Babesia bovis* prevalence, where a shift in dipping programme from intensive to strategic occurs, are largely altered in the first four years. In the first year 21.8% of the cattle receive a primary infection, resulting in 13% of the cows dying from an acute death leaving 67.8% of the breeding cows at year end, of which 24.9% are immune. Figure 5.16 illustrates a mean number of breeding cows holds at 68 animals in the first year. The herd in the second year experiences a 17.3% increase in primary infections and 10.7% more acute deaths occur when compared with the first year. Resultantly, 57.2% of the cattle remain at year end, of which 57.6% are immune. Primary infections and acute deaths in the third year reflect the results of the second where 39.9% of the herd experience primary infections and 24% of the cattle are lost to acute deaths. Resultantly, the herd at year end is at its lowest for the fifteen year period holding at 56.3%, depicted by an average of 56 animals in Figure 5.16. However, the proportion of remaining cattle which are immune holds at 88.3%. In the fourth year, the herd experiences 28.6% primary infections, the first decrease. Resultantly, fewer acute deaths occur where 17.7% of the cows are lost and mean number of breeding cows remains at 63 animals by the end of the year, of which 98% of the remaining cattle have seroconverted. From the fourth year, the number of cattle incurring a primary infection decrease while the amount of cattle remaining in the herd at year end increases. Primary infections decrease from 19.9% in the fifth year to 9.4% in the fifteenth. The mean number of remaining cattle in the herd increases from 69 in the fifth year to 76 in the fifteenth.

Herd numbers are drastically affected in the first three years since the proportion of immune heifers entering the herd are low, contributing towards a greater naive population of breeding cattle. In the first year, 93.2% of replacement heifers consist of retained heifers. However, since they were born two years before in an intensive dipping programme, the proportion of immune heifers is 16%. The replacement requirements in the second year is the highest, but retained heifers make up 75.9% of the amount. This is due to these heifers coming from the weaned cohort from the previous year where the weaning rate was the greatest, as seen in Figure 5.16 where the mean number of calves

weaned is 81. The proportion of immune heifers in the second year is 23.9%. However, in the third and fourth year, replacement heifers comprised of retained heifers were at their lowest since they belonged to the calving season occurring in the second and third year. Resultantly, purchased heifers were greatest in the third and fourth years consisting 37.7% and 36.6% of the required replacement heifers. Replacement heifer requirements decrease according to the increasing breeding herd numbers from the fourth year onwards. The composition of replacement heifers consists of an increase of retained heifers from 70.9% to 92.2% and a decrease of purchase heifers from 36.6% to 7.7% from the fourth to the fifteenth year. The proportion of immune heifers entering the herd increases from 39.2% to 53.7% concurrently. However, standard deviations ranging from 4.1 to 9.7 indicate variations in the proportion of immune heifers entering the herd due to the simulations results where the unknown immunity status of purchased heifers occur.

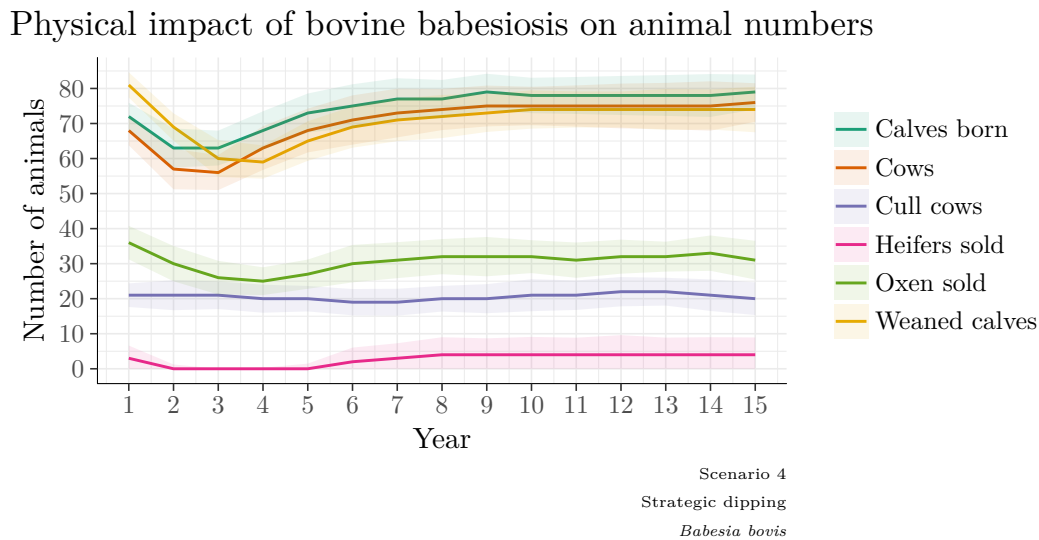


Figure 5.16: Composition of mean animal numbers in Scenario 4 of a strategic dipping strategy challenged with *Babesia bovis*.

The calving rate follows the breeding herd shock experienced in the first three years. Figure 5.16 delineates the decrease in the mean number of calves born from 72 calves in the first to 63 in the third year, a corresponding calving rates from 72.1% in the first to 63.4% in the second and to 62.9% in the third year. The fourth year experiences an increase in the calving rate by 5.4%. Hereafter, a continuous incline towards a calving rate of 79% is achieved in the fifteenth year. The weaning rate reflects the trend of the calving rate. The first year of weaning experienced the greatest weaning rate of 81.2% due to the calves having been born in the previous year of an intensive dipping programme and a low *Babesia bovis* prevalence. The weaning rate continues to decrease from the second to the fourth year from 69.1% to 59.3%. An increase of 5.5% is experienced in the fifth year following the calves born in the previous year. The weaning rate continues to increase until an annual average of 74% is achieved in the ninth to fifteenth year. The proportion of immune calves weaned increase from 10.3% in the first year to 44% in the fourth year. An average 46.2% of calves weaned have seroconverted in the fifth to fifteenth year. Despite the increase in immune weaners produced, an average of 12.1% of weaners die of disease induced acute deaths per year in the second to fifteenth year. The proportion of weaners lost due to acute deaths in the first year is 6.8%. The average number of oxen sold is greatest in the first year where 37 animals are sold. The mean number of oxen sold decrease in the following three years where 30 are sold in the second year

and 26 animals in the third and fourth year, respectively. Oxen sales increase to an average of 32 from the seventh year onwards. Heifer sales decrease from a mean number of 3 animals in the first year to 0 for the following four years due to the high replacement requirements. A steady increase in heifer sales is seen from the fifth to the fifteenth year ranging between two to five animals.

5.3 Economic impacts and financial analyses

The physical impact that bovine babesiosis has on the mean number of breeding cows remaining in a herd by the end of each simulated year and the number of oxen, heifers and cull cows sold are presented and discussed in section 5.2. The composition of remaining breeding cows for each year end and the mean number of animals sold during the year remain relatively similar for either the intensive or strategic dipping programmes for each respective scenario concerned with *Babesia bigemina* infections. However, increasing primary infections incurred for strategic dipping programmes lead to augmentations in acute deaths, collective weight loss and the treatment of mild and severe clinical cases as oppose to those experienced in intensive management systems. The structure of the breeding herd and the mean numbers of oxen, heifers and cull cows sold differ between dipping strategies in either scenarios concerning *Babesia bovis* infections. This is largely attributed to the virulence of such *Babesia bovis* infections.

In this section, the economic impact associated with bovine babesiosis, caused by either respective parasite, for each scenario and dipping strategy are presented and discussed. All failure cost cash outflows directly related to a disease incident, such as treatment, recovery feed and compensatory growth feed expenditures are included. Furthermore, the failure cost component includes the non-cash outflow costs. These are the value of weight lost by a recovering animal or that of a dead one. Failure costs are summed with the preventive costs, dipping, to attain a final value pertaining to the economic impact of the disease in each respective year. In this section the economic impacts of bovine babesiosis are presented for each dipping strategy and compared, respective of scenario and *Babesia* infection. Financial results are collected during the 100 iterations and are averaged. The economic impact is presented as the discounted costs incurred during the fifteen year simulation. This section also include the financial analysis of each dipping strategy per scenario per parasite. The financial analysis includes all cash flows concerned with the production of beef weaners and a stable breeding herd. These cash outflows include feed, pregnancy testing and disease related expenditures. Cash inflows are a result of oxen, heifers and cull cows sold. The financial impact of bovine babesiosis is reflected in the *NPV* since the cash flow may be altered as a result of disease occurrence. The *NPV* for each scenario per dipping strategy per parasite infection as well as the *IRR* is presented. Values in parentheses for the discounted economic impact and *NPV* are the 0.05 and 0.95 percentiles.

5.3.1 Scenarios concerning a *Babesia bigemina* infection for intensive and strategic dipping

Scenario 1

The undiscounted economic impact of *Babesia bigemina* induced bovine babesiosis for either dipping strategy are presented in Figure 5.17. The discounted economic impact for intensive and strategic dipping programmes over fifteen years are R93 640.34 (R68 704.47; R127 369.66) and R82 082.86 (R57 188.84; R110 415.17), respectively. The largest cost component of the economic impacts incurred is made of the value of weight lost due to either acute deaths or decreased weight gains in animals suffering mild or severe infections. The value of weight lost cost component consists 66.7% of the total economic impact for an intensive dipping programme and 75.1% for strategic dipping. Treatment costs for intensive dipping comprised 8.6% of the total economic impact and 9.4% for the strategic. Dipping expenditures incurred made up 21.2% in the intensive dipping strategy and 10.9% in the strategic programme. The proportion of compensatory growth feed costs are greater than those of recovery feed costs for both dipping programmes. Compensatory growth feed costs consisted of 3.1% and 3.5% while recovery feed costs were 0.9% and 1.1% of the total economic impact in intensive and strategic dipping programmes, respectively. The economic impact for strategic dipping is greatest in the first year at R10 437.72, and then ranges between R6 563.36 and R8 560.61 from the second to the fifteenth year. The economic impact incurred for intensive dipping ranged between R7 730.11 and R10 494.39 during the simulated years. The discounted costs avoided by adopting a strategic dipping programme where a 90% *Babesia bigemina* seroprevalence in the first year exists is R11 557.48. However, despite the greater economic impact occurring in the intensive dipping programme, the *NPV* and *IRR* results are greater than those of strategic dipping. These results are summarised in Table 5.1.

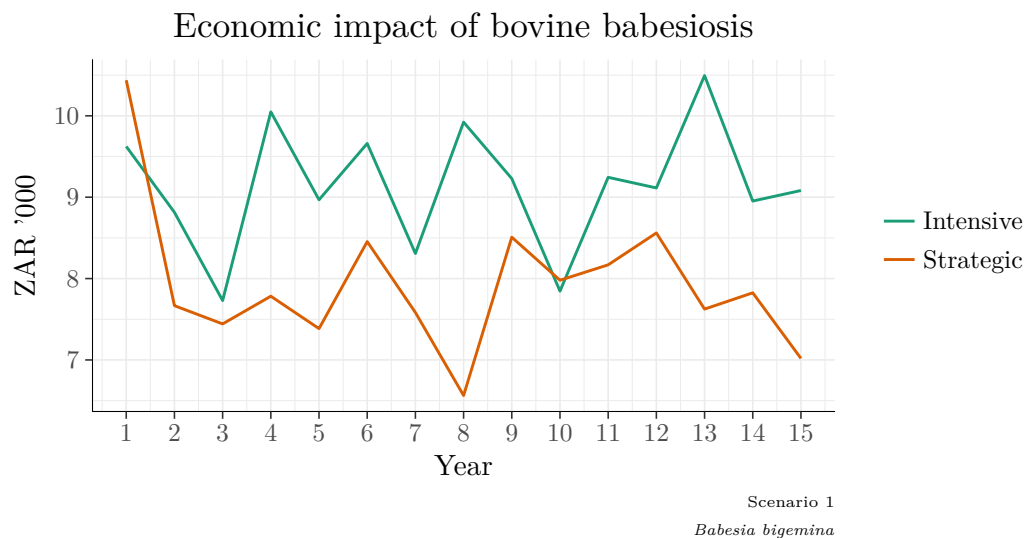


Figure 5.17: Undiscounted economic impact incurred in intensive and strategic dipping strategies for Scenario 1 concerning *Babesia bigemina*.

Table 5.1: Financial analysis of dipping strategies in Scenario 1 concerning *Babesia bigemina*.

Financial indicator	Dipping strategy	
	Intensive	Strategic
<i>NPV</i>	R3 071 363.47 (R2 924 288.00; R3 143 876.00)	R3 031 082.27 (R2 899 350.00; R3 098 274.00)
<i>IRR</i>	176%	173%

Scenario 2

The discounted economic impact for intensive and strategic dipping programmes over fifteen years in Scenario 2 concerning *Babesia bigemina* are R77 714.91 (R54 014.63; R112 117.62) and R90 911.55 (R68 125.65; R124 478.63), respectively. The largest cost component of the economic impacts incurred is made of the value of weight lost due to either acute deaths or decreased weight gains in animals suffering mild or severe infections. The value of weight lost cost component consists 62.8% of the total economic impact for an intensive dipping programme and 76.2% for strategic dipping. Treatment costs for intensive dipping comprised 8.9% of the total economic impact and 9.1% for the strategic. Dipping expenditures incurred made up 25.4% in the intensive dipping strategy and 10.2% in the strategic programme. The proportion of compensatory growth feed costs are greater than those of recovery feed costs for both dipping programmes. Compensatory growth feed costs consisted of 1.9% and 3.4% while recovery feed costs were 0.6% and 1% of the total economic impact in intensive and strategic dipping programmes, respectively. Figure 5.18 represents the undiscounted economic impact incurred for either dipping strategy. The economic impact of strategic dipping is greatest in the first year where a cost of R16 093.70 occurs. This cost is attributed to the increase in primary infections occurring, and resultantly the greatest number of clinical infections and acute deaths, with the change in dipping strategy. Treatment, recovery and compensatory feed costs are subsequently also the highest in the first year. The discounted costs avoided by adopting an intensive dipping programme where a 70% *Babesia bigemina* seroprevalence exists rather than strategic dipping is R13 196.64. However, the high costs and losses occurring in the first year for strategic dipping did not affect the net cash flow at year end. The net cash flow in the first year is R293 441.40, R1 967.10 greater than what is received in the tenth year. The net cash flow for intensive dipping ranged between R292 463.80 and R308 520.70. Financial results achieved in the simulations indicate that the *NPV* and *IRR* are both greatest for intensive dipping and are summarised in Table 5.2.

Table 5.2: Financial analysis of dipping strategies in Scenario 2 concerning *Babesia bigemina*.

Financial indicator	Dipping strategy	
	Intensive	Strategic
<i>NPV</i>	R3 068 862.99 (R2 925 360.00; R3 131 239.00)	R3 027 139.89 (R2 877 520.00; R3 104 559.00)
<i>IRR</i>	176%	171%

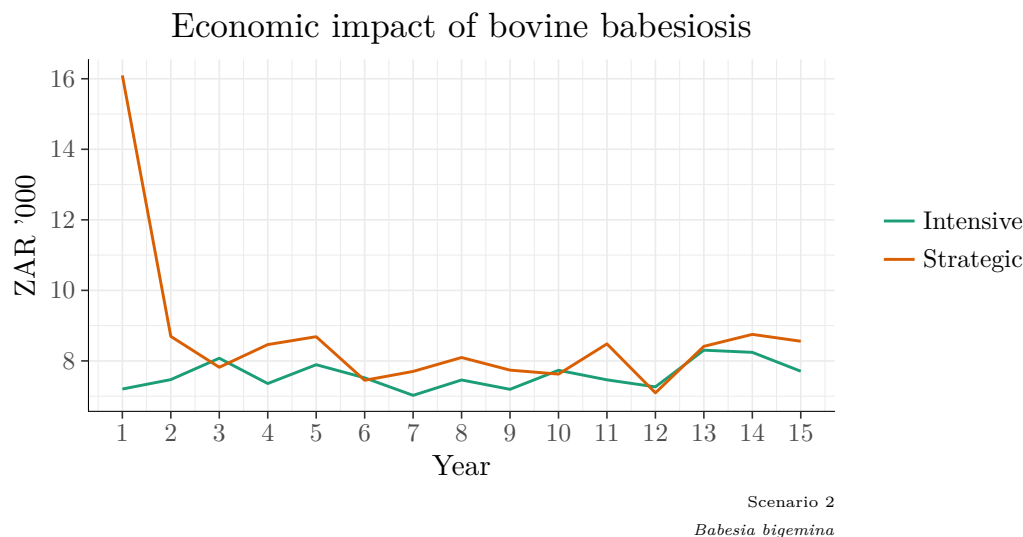


Figure 5.18: Undiscounted economic impact incurred in intensive and strategic dipping strategies for Scenario 2 concerning *Babesia bigemina*.

Scenario 3

The discounted economic impact for intensive and strategic dipping programmes over fifteen years in Scenario 3 concerning *Babesia bigemina* are R54 249.68 (R37 637.17; R77 953.47) and R95 625.75 (R69 427.63; R124 463.34), respectively. The largest cost component of the economic impact incurred is made of the value of weight lost due to either acute deaths or decreased weight gains in animals suffering mild or severe infections. The value of weight lost cost component consists 53.6% of the total economic impact for an intensive dipping programme and 75.8% for strategic dipping. Treatment costs for intensive dipping comprised 8.1% of the total economic impact and 9.5% for the strategic. Dipping expenditures incurred made up 36.4% in the intensive dipping strategy and 10.3% in the strategic programme. The proportion of compensatory growth feed costs are greater than those of recovery feed costs for both dipping programmes. Recovery and compensatory growth feed costs for intensive dipping composed a very small proportion of the total economic impact at 0.3% and 0.9%, respectively. These costs were comparatively larger for strategic dipping resulting in 1% of recovery feed and 3.4% of compensatory growth feed costs making up the total economic impact. Figure 5.19 represents the undiscounted economic impact incurred for either dipping strategy for each year. The economic impact of strategic dipping is greatest in the first year where a cost of R20 317.48 occurs, decreasing to R12 021.92 in the second year. The high start up costs experienced in the first two years is attributed to the increase in primary infections occurring, and resultantly the greatest number of clinical infections and acute deaths, with the change in dipping strategy. Treatment, recovery and compensatory feed costs are subsequently also the highest in the first and second year. From the third to the fifteenth year, the economic impacts for strategic dipping range between R7 208.20 and R8 463.84. The economic impacts for intensive dipping are steady in each year, ranging between R4 834.45 and R6 202.80. The discounted costs avoided by adopting an intensive dipping programme where a 40% *Babesia bigemina* seroprevalence exists rather than strategic dipping is R41 376.06. However, the high costs and losses occurring in the first two years of the herd which are strategically dipped did not affect the net cash flow for the respective year ends. The net cash flow in the first year is R298 646.70

and greater than the R290 756.00 received in the eighth year. Net cash flows for strategic dipping ranged between R290 756.00 and R303 809.30. The net cash flow for intensive dipping ranged between R292 197.30 and R308 777.80. Financial results achieved in the simulations indicate that the *NPV* and *IRR* are both greatest for intensive dipping. Financial indicators are greater for intensive dipping due to fewer disease related cash outflows and greater inflows as a result of more animals reaching the market compared with the greater disease related cash outflows and fewer animals sold in the strategic dipping simulations. The financial indicators are summarised in Table 5.3.

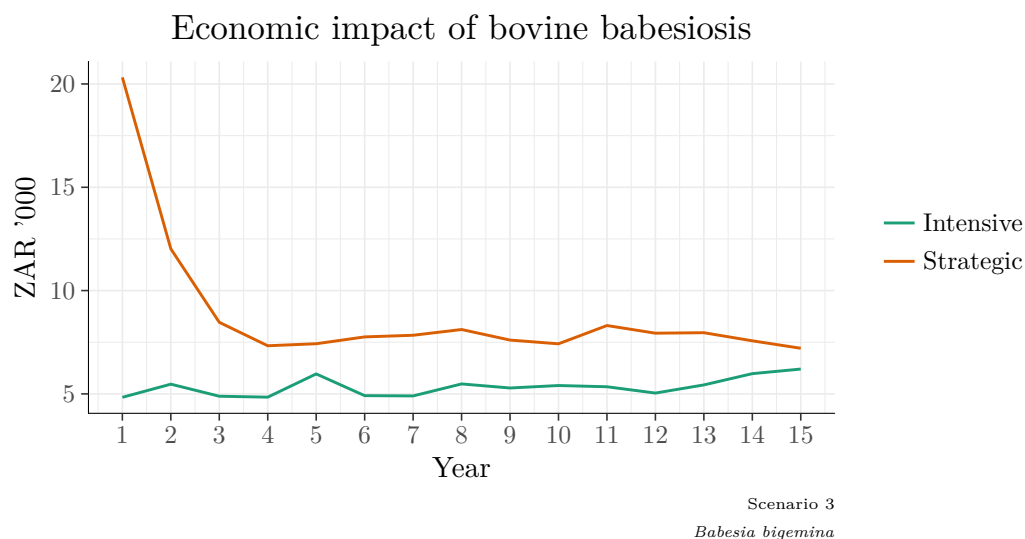


Figure 5.19: Undiscounted economic impact incurred in intensive and strategic dipping strategies for Scenario 3 concerning *Babesia bigemina*.

Table 5.3: Financial analysis of dipping strategies in Scenario 3 concerning *Babesia bigemina*.

Financial indicator	Dipping strategy	
	Intensive	Strategic
<i>NPV</i>	R3 089 452.73 (R2 940 499.00; R3 154 015.00)	R3 039 084.97 (2 884 600.00; R3 118 685.00)
<i>IRR</i>	177%	172%

Scenario 4

The discounted economic impact for intensive and strategic dipping programmes over fifteen years in Scenario 4 concerning *Babesia bigemina* are R30 294.31 (R21 953.44; R43 100.89) and R95 679.96 (R66 935.95; R127 650.55), respectively. The largest cost component of the economic impact incurred is made of the value of weight lost due to either acute deaths or decreased weight gains in animals suffering mild or severe infections. The value of weight lost cost component consists 28.7% of the total economic impact for an intensive dipping programme and 75.9% for strategic dipping. Treatment costs for intensive dipping comprised 4.5% of the total economic impact and 9.8% for the strategic. Dipping expenditures incurred made up 65.8% in the intensive dipping

strategy and 10.2% in the strategic programme. The proportion of compensatory growth feed costs are greater than those of recovery feed costs for both dipping programmes. Recovery and compensatory growth feed costs for intensive dipping composed a very small proportion of the total economic impact at 0.1% and 1%, respectively. These costs were comparatively larger for strategic dipping resulting in 0.3% of recovery feed and 3.2% of compensatory growth feed costs making up the total economic impact. Figure 5.19 represents the undiscounted economic impact incurred for either dipping strategy for each year. The economic impact of strategic dipping is greatest in the second year where a cost of R18 907.87 occurs. The second two largest economic impacts were experienced in the first and second year of R10 197.11 and R11 801.18, respectively. These high economic impacts experienced are a result of the increasing primary infections experienced in the breeding herd where 22.5%, 41.3% and 14.5% of the breeding cows are infected in the concurring years. Resultantly, the greatest number of clinical infections and acute deaths, with the change in dipping strategy. Treatment, recovery and compensatory feed costs are subsequently also the highest in the first three years. From the fourth to the fifteenth year, strategic dipping economic impacts range between R6 973.59 and R9 350.85. Economic impacts for intensive dipping are lower and stable, ranging between R2 631.66 and R3 296.48. The discounted costs avoided by adopting an intensive dipping programme where a 10% *Babesia bigemina* seroprevalence exists rather than strategic dipping is R65 385.65. The high economic impacts occurring in the first three years in a herd which is strategically dipped did not affect the net cash flow for the respective year ends. The net cash flow in the first years are R298 211.90, R297 808.50, R289 940.20 and the range in net cash flow for the fifteen year period is between R286 413.30 and R304 229.10. The net cash flow for intensive dipping ranged between R293 195.80 and R314 219.80. Financial results achieved in the simulations indicate that the *NPV* and *IRR* are both greatest for intensive dipping. Financial indicators are greater for intensive dipping due to fewer disease related cash outflows and greater inflows as a result of more animals reaching the market compared with the greater disease related cash outflows and fewer animals sold in strategic dipping simulations. The financial indicators are summarised in Table 5.4.

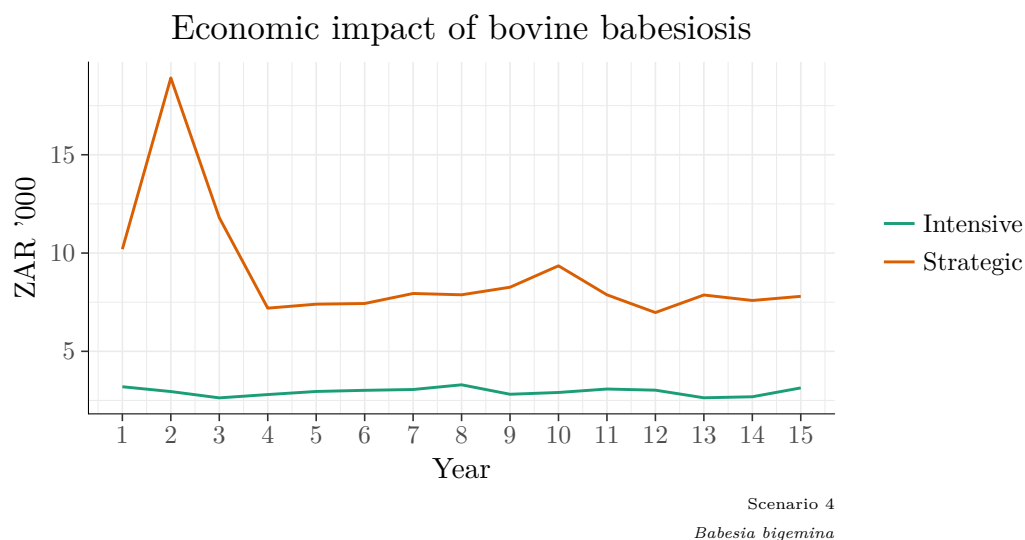


Figure 5.20: Undiscounted economic impact incurred in intensive and strategic dipping strategies for Scenario 4 concerning *Babesia bigemina*.

Table 5.4: Financial analysis of dipping strategies in Scenario 4 concerning *Babesia bigemina*.

Financial indicator	Dipping strategy	
	Intensive	Strategic
<i>NPV</i>	R3 112 616.95 (R2 980 869.00; R3 176 677.00)	R3 029 923.35 (R2 873 067.00; R3 097 701.00)
<i>IRR</i>	175%	172%

5.3.2 Scenarios concerning a *Babesia bovis* infection for intensive and strategic dipping

Scenario 1

The discounted economic impact for intensive and strategic dipping programmes over fifteen years in Scenario 1 concerned with *Babesia bovis* are R1 138 522.41 (R832 058.70; R1 537 356.30) and R1 255 592.16 (R992 705.80; R1 686 447.50), respectively. The largest cost component of the economic impact incurred is made up of the value of weight lost due to either acute deaths or decreased weight gains in animals suffering from mild or severe infections. The value of weight lost cost component consists 93.9% and 94.7% of the total economic impact incurred in the intensive and strategic dipping programmes, respectively. Treatment costs for intensive dipping comprised 2.4% of the economic impact and 2.2% for strategic dipping. Dipping expenditures incurred made up 1.7% in the intensive dipping strategy and 0.7% in the strategic programme. Recovery feed costs are greater than compensatory feed costs due to the longer recovery periods occurring in *Babesia bovis* infections. The proportion of recovery feed costs making up the total economic impact are 1.1% and 1.5% for the intensive and strategic dipping programmes. Compensatory growth feed costs are 0.7% and 0.9%, respectively. Economic impacts are lowest in the first four years of an intensive dipping strategy. Figure 5.21 illustrates the economic impacts incurred in the first year R94 883.43 increasing towards R107 035.96 in the fourth. The increasing cost incurred in the form of weight loss value is largely attributed to the increasing primary infections occurring amongst the breeding cows of which 2.5% in the first year augmenting towards 8% in the sixth year succumb to acute deaths. The economic impact of this cost component rises from R17 225.91 to R36 632.77 during the first six years. In the concurring years treatment costs concerning the breeding cows increase from R610.94 to R1 626.88 with the increase of primary infections. Costs in weight loss of the breeding cows stabilise in the seventh year onwards as the mean proportion of acute deaths is steady at 8.4%. The value of weight loss occurring in calves and weaners remains constant during the simulated period, however. The economic impact incurred in the strategic dipping programme is greatest in the first three years. Figure 5.21 delineates the economic impact in the first year is R163 139.20 decreasing towards R126 738.10 in the third year. Although the breeding herd remains relatively constant during the fifteen year simulation, the less intensive dipping strategy does incur a economic impact in order for 99.9% of the remaining cattle to acquire immunity which arises a cost of weight loss and mortality of R34 391.74, R29 517.35 and R32 824.16 in the first, second and third year. The increase in primary infections is felt greatest amongst the oxen and heifer cohorts where the sum of economic impact incurred in the first three years is R120 205.02, R84 146.65 and R84 630.81. Overall, the economic impacts associated with the calf, oxen and heifer cohorts are greater in the strategic dipping programmes comprising 74.2% of the total economic impact compared with 63.6% in intensive dipping. The discounted costs avoided by adopting an intensive dipping programme rather than that of the strategic is R117 069.74.

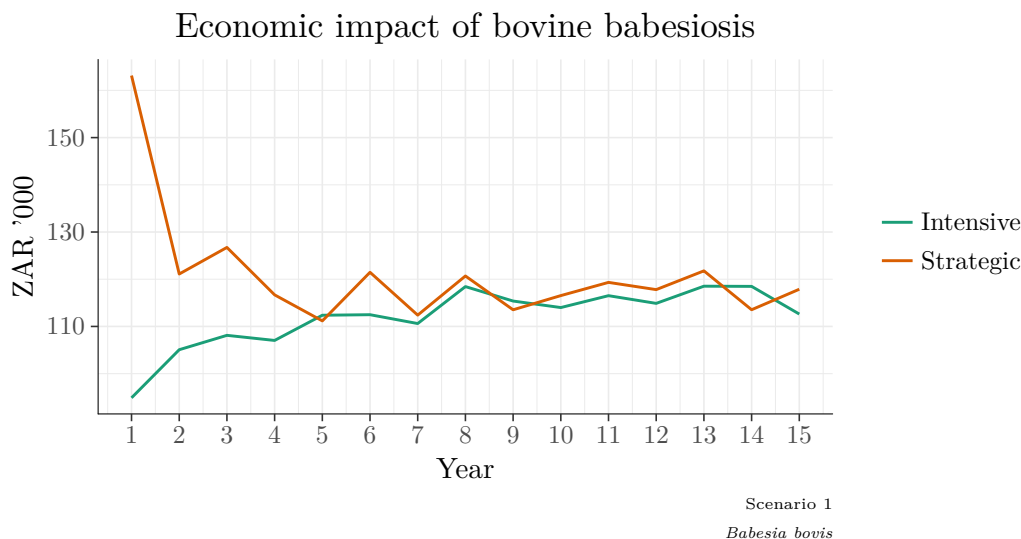


Figure 5.21: Undiscounted economic impact incurred in intensive and strategic dipping strategies for Scenario 1 concerning *Babesia bovis*.

Despite the greater discounted economic impact associated with a strategic dipping programme, the *NPV* of this strategy is greater than that of the intensive. The increased proportion of immune replacement heifers entering the herd in subsequent years transpires to a lesser disease related cash outflow of R66 429.88 compared with R69 980.49 for strategic and intensive dipping, respectively. Furthermore, a greater mean number of heifers are sold due to a stable mean number of breeding cows at year end compared with the decreasing numbers in the intensive dipping programmes. Discounted cash inflows are R4 402 395.91 and R4 370 572.66 for strategic and intensive dipping, respectively. However, the *IRR* for intensive dipping is greater than that of the strategic programme. A cross-over rate of 7.891% implies that while the interest rate remains below or equal to the cross-over rate it is more profitable to choose strategic dipping. If the interest rate increases above the cross-over rate it is more profitable to choose the intensive dipping strategy. The *NPV* and *IRR* for each strategy are summarised in Table 5.5.

Table 5.5: Financial analysis of dipping strategies in Scenario 1 concerning *Babesia bovis*.

Financial indicator	Dipping strategy	
	Intensive	Strategic
<i>NPV</i>	R1 680 028.32 (R1 355 554.00; R1 907 940.00)	R1 890 547.62 (R1 642 198.00; R2 109 063.00)
<i>IRR</i>	118%	117%

Scenario 2

The discounted economic impact for intensive and strategic dipping programmes over fifteen years in Scenario 2 concerning *Babesia bovis* are R893 786.48 (R658 753.10; R1 219 496.70) and R1 327 598.93 (R1 054 928.00; R1 744 676.00), respectively. The largest cost component of the economic impact incurred is made of the value of weight lost due to either acute deaths or decreased

weight gains in animals suffering mild or severe infections. The value of weight lost cost component consists 93.6% of the total economic impact for an intensive dipping programme and 94.7% for strategic dipping. Treatment costs for intensive dipping comprised 2.5% of the total economic impact and 2.4% for the strategic. Dipping expenditures incurred made up 2.2% in the intensive dipping strategy and 0.7% in the strategic programme. The proportion of recovery feed costs are greater than those of compensatory growth feed costs for both dipping programmes due to the longer recovery periods occurring with *Babesia bovis* infections. Recovery feed costs consisted of 0.7% and 1.4% while compensatory growth feed costs were 0.5% and 0.9% of the total economic impact in intensive and strategic dipping programmes, respectively. Figure 5.22 represents the undiscounted economic impact incurred for either dipping strategy. The economic impact of strategic dipping is greatest in the first two years where a cost of R236 869.50 and R138 871.10 occurs. This cost is attributed to the increase in primary infections occurring, and resultantly the greatest number of clinical infections and acute deaths of which 14.4% and 11.3% the breeding cows succumbed to in the first and second year as a result in the change in dipping strategy. Treatment, recovery and compensatory feed costs are subsequently also the highest in the first and second year. Economic impacts incurring in the calf, oxen and heifer cohorts make up 71.1% of the total economic impact. This in comparison with the same cohorts of intensive dipping consist only 50.9% of the total economic impact. The discounted costs avoided by adopting an intensive dipping programme where a 70% *Babesia bovis* seroprevalence exists rather than strategic dipping is R433 811.45.

The net cash flow for an intensive dipping programme ranges between R174 760.80 and R216 902.3. The net cash flow for strategic dipping is affected by the reduced number of animals reaching the sale in the first to third year. The net cash flow in the first year is R107 642.30 in the first year increasing towards R157 315.50 in the fifth. From the sixth to the fifteenth year the net cash flow ranges between R167 109.60 and R180 394.70. Discounted disease related expenditures as well as production related expenditures are greatest in strategic dipping. Breeding cows within strategic dipping programmes acquire immunity which transpires to greater feed related expenditures compared with the intensive strategy. Total non-disease related outflows are R2 623 899.00 and R2 721 524.00 for intensive and strategic dipping, respectively. Furthermore, as calf, oxen and heifer cohorts make up the largest proportion of the economic impact, as do the disease related expenditures where 65% of the discounted R68 519.16 total disease related expenditure is attributed to these groups. A smaller 38.7% of the R56 861.76 total discounted disease related expenditure of intensive dipping is attributed to the calf, oxen and heifer cohorts in comparison. The lower number of animals reaching the market in a strategic dipping programme contributes to a lower cash inflow. Lower cash inflows coupled with higher disease and production related cash outflows yields lower net cash inflows in comparison with the intensive strategy. Financial results achieved in the simulations indicate that the *NPV* and *IRR* are both greatest for intensive dipping and are summarised in Table 5.6.

Table 5.6: Financial analysis of dipping strategies in Scenario 2 concerning *Babesia bovis*.

Financial indicator	Dipping strategy	
	Intensive	Strategic
<i>NPV</i>	R2 007 261.86 (R1 804 206.00; R2 153 423.00)	R1 835 145.86 (R1 664 929.00; R1 982 919.00)
<i>IRR</i>	138%	89%

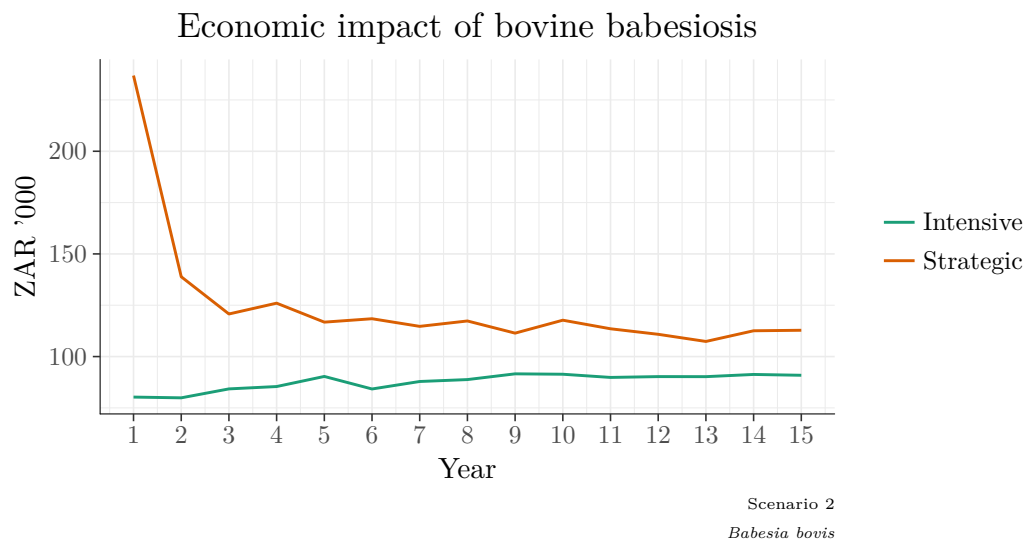


Figure 5.22: Undiscounted economic impact incurred in intensive and strategic dipping strategies for Scenario 2 concerning *Babesia bovis*.

Scenario 3

Where a *Babesia bovis* seroprevalence of 40% exists in the first year, choosing to dip intensively realise a lower economic impact compared with the strategic dipping programme. The discounted economic impact incurred for the intensive dipping is R531 227.72 (R385 376.10; R720 908.40) and R1 481 803.22 (R1 156 874.00; R2 011 045.00) for strategic dipping. The largest cost component of the economic impact incurred is made of the value of weight lost due to either acute deaths or decreased weight gains in animals suffering mild or severe infections. The value of weight lost cost component consists 92.4% of the total economic impact for an intensive dipping programme and 94.9% for strategic dipping. Treatment costs for intensive dipping comprised 2.6% of the total economic impact and 2.3% for the strategic. Dipping expenditures incurred made up 3.7% in the intensive dipping strategy and 0.7% in the strategic programme. The proportion of recovery feed costs are greater than those of compensatory growth feed costs for both dipping programmes due to the longer recovery periods occurring with *Babesia bovis* infections. Recovery feed costs consisted of 0.3% and 1.3% while compensatory growth feed costs were 0.2% and 0.8% of the total economic impact in intensive and strategic dipping programmes, respectively. Figure 5.23 represents the undiscounted economic impact incurred for either dipping strategy. The economic impact of strategic dipping is greatest in the first three years where a cost of R303 183.60, R189 376.50 and R133 721.00 occurs. This cost is attributed to the increase in primary infections occurring. Adopting a strategic dipping programme in the first year where approximately 60% of the breeding cows are naive allows for the 40% to receive a primary infection, transpiring to 26.1% of them succumbing to an acute death. The decrease in primary infections to 32.6% and 10.6% in the second and third year are in accordance with the decreasing economic impact. Treatment, recovery and compensatory feed costs are subsequently also the highest in the first, second and third year. The economic impact of strategic dipping in each year stabilises from the fifth year onwards, ranging between R113 867.20 and R125 245.30. The economic impacts in each year for intensive dipping is stable for all fifteen years, however, and ranges between R46 606.89 and R55 658.28. Economic impacts incurring in the calf, oxen and heifer cohorts of strategic dipping make

up 63.7% of the total economic impact. This in comparison with the same cohorts of intensive dipping consists only 41.2% of the total financial impact is greater. The discounted costs avoided by adopting an intensive dipping programme where a 40% *Babesia bovis* seroprevalence rather than strategic dipping is R950 575.50.

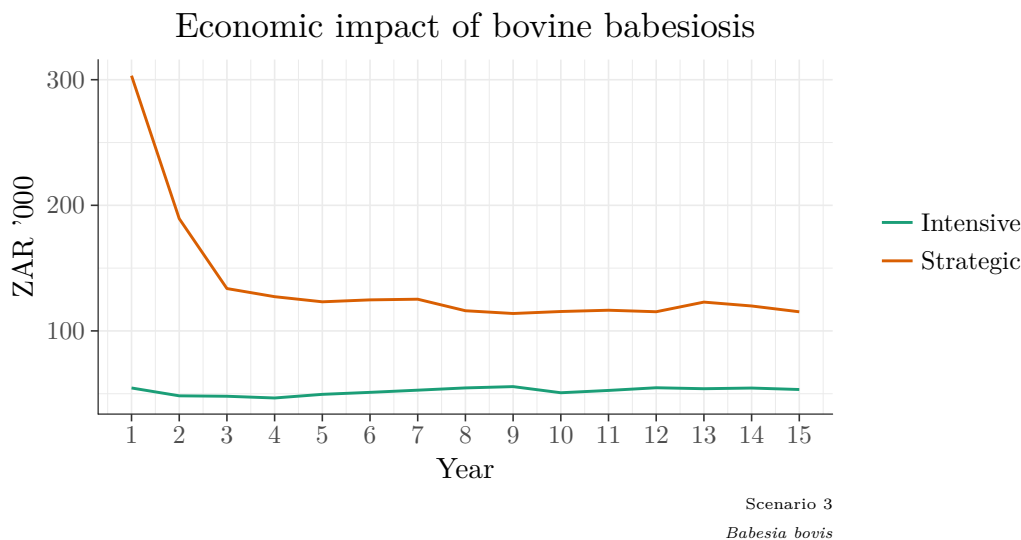


Figure 5.23: Undiscounted economic impact incurred in intensive and strategic dipping strategies for Scenario 3 concerning *Babesia bovis*.

The net cash flow for an intensive dipping programme ranges between R234 081.60 and R264 062.80. The net cash flow for strategic dipping is affected largely in the first five years. Despite the highest number of oxen sold in the first year, reflected in the cash inflow of R419 214.80, cash outflows were also very high due to disease related expenditure and the purchase of replacement heifers of R12 287.89 and R107 982.94, respectively. The net cash inflow achieved in the first year is R56 817.18. In the second and third year, replacement heifer purchases and disease related expenditures decreased consisted 32% and 29.8% of the total outflows. An average number of 26 oxen sold in concurring years yielded low cash inflows. Net cash inflows in the second and third year are R65 141.85 and R69 703.97. Increasing oxen and heifer sales occurring in following years contributed to an increasing cash inflow. However, the increasing immune breeding cows requiring higher feed expenditures, contributing towards the non-disease related discounted cash outflow of R2 781 526, coupled with high disease related expenditures of R72 942.61 where 58.8% is attributed to the calf, oxen and heifer cohorts are not favourable for the net cash inflows. Intensive dipping realises a lower non-disease related discounted cash outflow of R2 591 229 , coupled with a lower disease realted discounted cash outflow of R40 236.74. A greater number of animals reaching the market act in favour of a more beneficial net cash inflows. Therefore, the financial results achieved in the simulations indicate that the *NPV* and *IRR* are both greatest for intensive dipping when compared with strategic dipping in Scenario 3. Financial indicators are summarised in Table 5.7.

Table 5.7: Financial analysis of dipping strategies in Scenario 3 concerning *Babesia bovis*.

Financial indicator	Dipping strategy	
	Intensive	Strategic
<i>NPV</i>	R2 487 489.76 (R2 317 004.00; R2 590 337.00)	R1 738 386.61 (R1 548 861.00; R1 913 451.00)
<i>IRR</i>	156%	59%

Scenario 4

Adopting a strategic dipping strategy where a minimal state of disease exists, such that the presence of 10% *Babesia bovis* seroprevalence exists in the breeding cows, incurs the greatest economic impact. The discounted economic impact pertaining to a fifteen year long simulation is R1 492 277.39 (R1 132 682.00; R2 032 883.00) opposed to a much lower R177 266.66 (R131 312.40; R245 381.60) for intensive dipping. Figure 5.24 delineates the economic impact of strategic dipping occurring in the first year at R157 765.60. The high economic impact in the first year is associated with the increase in primary infections where 21.8% of the breeding cows are infected. Subsequently, 13% of the breeding cows are lost due to acute deaths. In the same year, 6.8% of the weaners die from an acute death. The second year of strategic dipping experiences the greatest economic impact of R244 864.10. Replacement heifers entering the herd in the second year consisted of 16% immune animals. The proportion of immune breeding cows remaining at the end of the first year is also low, 26.9%. An increasing infection rate and a large proportion of naive cattle resulted in 39.1% of the breeding cows receiving a primary infection. Resultantly, 23.7% of the cows died from an acute death. The loss of weaners in the second is also high where 12.1% succumbed to an acute death. The high proportions of primary infections, transpiring to mild or severe clinical infections as well as acute deaths contributes to the high economic impact incurred in the second year of strategic dipping. The economic impact decreases to R216 295.30 in the third year, towards R123 149.20 in the seventh year. From the eighth year onwards, the economic impact of strategic dipping ranges between R109 319.80 and R121 922.60. The much lower economic impact of intensive dipping ranges from R15 501.68 to R18 676.27. For both strategies, the value of weight lost either by acute deaths or decreased weight gains during mild or severe infections are the greatest cost component of the total economic impact. This cost component consisted of 85.5% and 94.9% for intensive and strategic dipping programmes, respectively. Treatment costs for intensive dipping comprised 2.2% of the total economic impact and 2.4% for the strategic. Dipping expenditures incurred made up 11.1% in the intensive dipping strategy and 0.6% in the strategic programme. The proportion of recovery feed costs are greater than those of compensatory growth feed costs for both dipping programmes. Recovery and compensatory growth feed costs for intensive dipping composed a very small proportion of the total economic impact at 0.1%, respectively. These costs were comparatively larger for strategic dipping resulting in 1.3% of recovery feed and 0.8% of compensatory growth feed costs making up the total financial impact. The discounted economic impact avoided by adopting the intensive dipping strategy opposed to the strategic programme is R1 315 051.69.

Net cash flows for strategic dipping are largely affected in the second to fifth year due to the low mean number of animals reaching the market as illustrated in Figure 5.16. Undiscounted cash inflows during these years are R392 230.80, R352 256.90, R339 829.40 and R356 557.50. Disease related expenditures and the costs of purchased heifers made up 30.2%, 42.5%, 38.6% and 28.8% of the undiscounted cash outflows during the concurring years, respectively. Low cash inflows due

to fewer animals reaching the market coupled high disease related expenditures and purchased replacement heifer costs leads to low net cash flows. From the ninth year onwards the proportion of disease related expenditure and the cost of purchased replacement heifers comprised 10.1% of the cash outflows on average. Calf, oxen and heifer disease related disease cash outflows consisted 54.9% of the discounted disease related cash outflow of R73 742.95 for strategic dipping as opposed to 12.9% of R25 830.65 for intensive dipping. The financial results achieved in the simulations indicate that the *NPV* and *IRR* are both greatest for intensive dipping when compared with strategic dipping in Scenario 4. Financial indicators are summarised in Table 5.8.

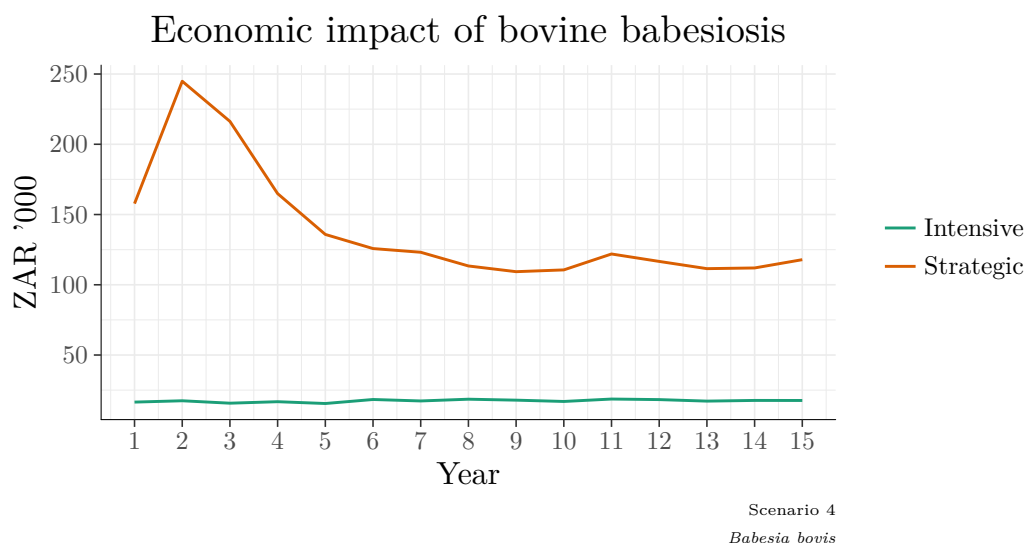


Figure 5.24: Undiscounted economic impact incurred in intensive and strategic dipping strategies for Scenario 4 concerning *Babesia bovis*.

Table 5.8: Financial analysis of dipping strategies in Scenario 4 concerning *Babesia bovis*.

Financial indicator	Dipping strategy	
	Intensive	Strategic
<i>NPV</i>	R2 946 083.66 (R2 769 249.00; R3 054 283.00)	R1 704 960.61 (R1 523 904.00; R1 895 826.00)
<i>IRR</i>	171%	82%

5.4 The financial effects of bovine babesiosis on production

Financial results of a healthy farm where no presence of bovine babesiosis exists indicates that the net cash flow will range between R299 159.70 and R322 186.50 during the fifteen year simulation. Disease related cash outflows pertain only to the dipping expenditure which ranges from R1 922.96 to R1 937.65 in the concurring years. The discounted net cash flow of a disease free farm is R3 130 452.56 and the discounted economic impact of bovine babesiosis is R19 812.46. Net cash flows of beef production are not drastically affected by *Babesia bigemina* induced bovine babesiosis. In comparison, *Babesia bovis* induced bovine babesiosis affects the net cash flow significantly. Comparisons of *NPV* estimates for beef producers challenged with *Babesia bigemina* and

Babesia bovis for each dipping programme and respective scenario are summarised in Table 5.9

Reduced *NPV* is greatest in Scenario 2 of intensive and strategic dipping when challenged with *Babesia bigemina*. The lowest reduction of *NPV* is experienced in Scenario 4 of intensive dipping and Scenario 3 of strategic dipping. The effect of *Babesia bigemina* induced bovine babesiosis on the *NPV*'s is always less for intensive dipping than that of strategic dipping.

When challenged with *Babesia bovis*, the *NPV* estimate for scenario 1 of strategic dipping is reduced by 6.7% less than that of an intensive dipping regime in comparison with a healthy farm. However, both *NPV* estimates for Scenario 1 are high as summarised in Table 5.9. However, for intensive dipping, the estimated *NPV* is reduced by less with a decreasing seroprevalence. In contrast, for each strategic dipping programme where a lesser seroprevalence exists in the first year translates to a greater reduction in the estimated *NPV*. Overall results indicate that a *Babesia bovis* challenge has a greater negative impact on the net cash flow as a result of fewer animals reaching the market.

Table 5.9: *NPV* comparisons with a healthy farm.

Parasite challenge	Scenario	Dipping strategy	<i>NPV</i>	$\Delta\%$ in <i>NPV</i>
None	Healthy farm	Intensive	R3 130 452.56	0%
		Strategic	R3 071 363.47	-1.9%
	1	Intensive	R3 031 082.27	-3.2%
		Strategic	R3 068 862.99	-2%
<i>Babesia bigemina</i>	2	Intensive	R3 027 139.89	-3.3%
		Strategic	R3 089 452.73	-1.3%
	3	Intensive	R3 039 084.97	-2.9%
		Strategic	R3 112 616.95	-0.6%
	4	Intensive	R3 029 923.35	-3.2%
		Strategic	R1 680 028.32	-46.3%
	1	Intensive	R1 890 547.62	-39.6%
		Strategic	R2 007 261.86	-35.9%
<i>Babesia bovis</i>	2	Intensive	R1 835 145.86	-41.4%
		Strategic	R2 487 489.76	-20.5%
	3	Intensive	R1 738 386.61	-44.4%
		Strategic	R2 946 083.66	-5.9%
	4	Intensive	R1 704 890.61	-45.5%
		Strategic		

5.5 Sensitivity analysis

Variables resulting in a change of 5.0% or less are considered to have little effect, and are therefore ignored. Sensitivity analysis results are summarised in Table 5.10 and 5.11.

Results pertaining to a *Babesia bigemina* infection in all four scenarios across both dipping strategies showed that *NPV* and *IRR* results are affected the most by a change in the beef price. On average, *NPV* and *IRR* results decreased by 19% and 14.2% and increased by 19.1% and 13.7%, respectively. A decrease in the beef price had little affect on the economic impact except for an intensive dipping strategy in Scenario 3 where a decrease of 5.2% is achieved. Changes in the

economic impact incurred as a result of a beef increase are not consistent, however, larger increases are achieved in strategic dipping of Scenario 1 and for both dipping programmes in Scenario 3. The increase and decrease of dipping expenditure had little effect on the *NPV* or the *IRR* for both dipping programmes. Intensive dipping strategies experience greater economic impact effects with a decrease or increase in the cost per dipped cow as the parasite prevalence decreases. The economic impact of strategic dipping strategies are not hugely affected by a change in the dipping price. Changes in the cost per treated animal had little effect on the economic impact, *NPV* and *IRR* across all scenarios for both dipping programmes. An increase of the conception rate had larger effects on the economic impacts incurred for strategic dipping compared with intensive dipping, ranging from increase from 7.5% to 15.6%. Only Scenario 1 of intensive dipping had a large increase of 7.5% on the economic impact. Little affect occurred in the other three scenarios of intensive dipping. Net present values increased between 8.3% and 8.9% for intensive dipping programme and 6.9% and 9.3% for strategic dipping. However, little affect is observed for Scenario 4 of the latter strategy. Internal rates of return were neither greatly affected by an increase in conception rates for all scenarios and dipping strategies. Calves weaned where the majority are seven months old had greater effects on the economic impacts of strategic dipping. Increases of 6.5%, 5.4% and 6.6% on the economic impact is incurred for Scenario 1, 3 and 4 for strategic dipping. The *NPV* and *IRR* are not largely affected in both intensive and strategic dipping for all scenarios. Calves weaned where the majority are five months old show a decrease in the economic impact for scenario one and two of intensive dipping where respective decreases of 8% and 5.8% are achieved. Comparatively, the economic impact is decreased in all scenarios of strategic dipping as a result of a greater proportion of younger calves weaned. Decreases range between 6.9% and 12.7%. Net present values and the *IRR* for all scenarios and dipping programmes are positively effected where an average increase of 7% and 11.6% occur for either dipping strategy, respectively.

Similarly to the above, the *NPV* and *IRR* with regards to a *Babesia bovis* prevalence are largely affected by a change in the beef prices for both dipping programmes in all scenarios. A decrease in the beef price reduced the *NPV* of intensive and strategic dipping by an average of 22.1% and 27.7%, respectively. An increase in the beef price show increase of the *NPV* by an average 21% for intensive dipping and 27.9% for strategic dipping. Internal rates of return decreased by a mean of 15.2% and 21% with a decrease in beef prices and increased by 15.4% and 19.7% with increased beef prices for intensive and strategic dipping programmes, respectively, across all scenarios. Overall results showed that a decrease in the beef price had little effect on the economic impact. An increase on the beef price, however, had an affect on the economic impact of intensive dipping in Scenario 1, 2, and 3. Changes in the dipping and treatment price had little affect on the economic impact, *NPV* and *IRR* for all scenarios and dipping strategies. As result of an increased conception rate, the largest rise of 5.7% in the economic impact occurred in Scenario 4 of strategic dipping. The effect of an increased conception rate show increases in the *NPV* of intensive dipping strategies. However, a lower parasite prevalence shows a decreasing sensitivity of the *NPV*. Strategic dipping *NPV*'s increased by an average of 31.6%. The sensitivity of the *IRR* also decreased with a lowering of seroprevalence in an intensive dipping strategy. Neither the economic impacts, *NPV* and *IRR* were hugely affected by an increased proportion of older calves at weaning. However, weaning the majority of calves at five months old had a greater affect on the economic impact of a strategic dipping programme. The economic impact is reduced by 13%, 11% 10.4% and 8.1% in Scenario 1, 2, 3 and 4. The economic impacts of an intensive dipping strategy is not largely affected in scenario three, but is decreased by 6.8%, 5.5% and 5.3% in Scenario 1, 2 and 4. Net present values for intensive dipping increased between a range of 6.8% and 12.4%. However, greater sensitivity is experienced in scenarios of greater *Babesia bovis* seroprevalence. The increase

of NPV 's for strategic dipping averaged at 15.3% and is greater than that of intensive dipping across all four scenarios. The IRR for intensive dipping increased by values between 12.2% and 16.1%. Strategic dipping IRR 's experienced increasing trends of increased values in scenarios of lower seroprevalence.

Table 5.10: Sensitivity analysis results concerning a *Babesia bigemina* challenge.

Δ input parameter	Indicator	$\Delta\%$ Scenario 1		$\Delta\%$ Scenario 2		$\Delta\%$ Scenario 3		$\Delta\%$ Scenario 4	
		Int.	Str.	Int.	Str.	Int.	Str.	Int.	Str.
$\mu Price_k \times 0.9$	Eco. imp.	-3.2%	1.7%	-3.5%	-1.6%	-5.2%	-1.1%	3.3%	3.7%
	NPV	-19.3%	-18.7%	-18.9%	-18.9%	-18.5%	-19.4%	-19.1%	-19.2%
	IRR	-14.2%	-13.9%	-14.2%	-13.5%	-13.6%	-16.3%	-13.7%	-14.0%
$\mu Price_k \times 1.1$	Eco. imp.	1.4%	5.4%	2.2%	1.5%	5.7%	9.2%	1.8%	3.6%
	NPV	18.9%	19.8%	18.5%	19.6%	19.0%	18.7%	18.6%	19.4%
	IRR	13.1%	13.3%	12.5%	14.0%	15.3%	12.2%	14.9%	14.5%
$dc \times 0.8$	Eco. imp.	0.9%	1.2%	-7.4%	-2.7%	-8.2%	-0.7%	-11.9%	0.9%
	NPV	-0.7%	0.3%	0.7%	1.0%	0.4%	0.3%	0.2%	0.0%
	IRR	0.0%	-0.6%	1.1%	0.6%	0.0%	0.0%	1.7%	-0.6%
$dc \times 1.2$	Eco. imp.	5.4%	5.1%	6.8%	1.9%	3.4%	-1.2%	14.9%	5.3%
	NPV	-0.4%	0.2%	-0.1%	0.4%	0.2%	-0.5%	-0.1%	0.0%
	IRR	0.0%	-1.2%	-1.7%	-0.6%	0.0%	-1.7%	1.7%	0.0%
$tr_n \times 0.9$	Eco. imp.	0.7%	0.5%	-1.0%	-2.8%	0.8%	0.3%	0.3%	2.1%
	NPV	-0.1%	0.6%	0.1%	-0.1%	0.1%	-0.1%	0.1%	-0.1%
	IRR	0.6%	1.2%	0.6%	-1.2%	0.0%	-0.6%	1.1%	0.6%
$tr_n \times 1.1$	Eco. imp.	1.6%	1.3%	3.4%	0.3%	5.0%	0.6%	4.2%	3.6%
	NPV	-0.1%	0.2%	-0.2%	0.4%	0.1%	-0.5%	-0.2%	-0.1%
	IRR	1.1%	-0.6%	0.0%	0.0%	-0.6%	-1.2%	1.1%	0.6%
$cc + 10\%$	Eco. imp.	7.4%	15.2%	2.0%	13.0%	3.5%	7.5%	2.5%	15.6%
	NPV	8.5%	9.1%	8.9%	9.3%	8.8%	8.3%	6.9%	1.3%
	IRR	-2.3%	-2.3%	-0.6%	-0.6%	-1.7%	-2.9%	0.0%	-2.3%
$be + 25\%$	Eco. imp.	2.6%	6.5%	-0.8%	0.6%	7.0%	5.4%	2.6%	6.6%
$bm - 20\%$	NPV	-1.7%	0.1%	-0.7%	-0.5%	-0.8%	-1.1%	-0.6%	-1.2%
$bl - 5\%$	IRR	-2.3%	-1.2%	-2.3%	-0.6%	-1.7%	-2.3%	-0.6%	-1.7%
$be - 55\%$	Eco. imp.	-8.0%	-11.4%	-5.8%	-12.7%	-2.9%	-12.1%	-1.3%	-6.9%
$bm - 20\%$	NPV	6.5%	7.5%	7.1%	7.8%	6.7%	6.8%	6.8%	6.7%
$bl + 75\%$	IRR	12.5%	11.6%	11.9%	12.3%	10.7%	10.5%	12.6%	10.5%

Table 5.11: Sensitivity analysis results concerning a *Babesia bovis* challenge.

Input parameter	Indicator	$\Delta\%$ Scenario 1		$\Delta\%$ Scenario 2		$\Delta\%$ Scenario 3		$\Delta\%$ Scenario 4	
		Int.	Str.	Int.	Str.	Int.	Str.	Int.	Str.
$\mu Price_k \times 0.9$	Eco. imp.	-1.8%	-2.9%	-4.8%	-0.4%	-3.2%	-4.5%	-6.7%	-1.7%
	NPV	-25.5%	-24.3%	-22.7%	-29.1%	-21.0%	-25.5%	-19.2%	-31.9%
	IRR	-15.3%	-18.8%	-18.1%	-21.3%	-14.1%	-16.9%	-13.5%	-26.8%
$\mu Price_k \times 1.1$	Eco. imp.	6.7%	2.2%	5.2%	3.4%	6.9%	3.0%	-0.4%	4.8%
	NPV	21.1%	27.0%	22.8%	23.5%	20.1%	30.5%	19.9%	30.5%
	IRR	15.3%	18.8%	15.9%	14.6%	14.7%	22.0%	15.8%	23.2%
$dc \times 0.8$	Eco. imp.	1.4%	-1.7%	0.2%	1.7%	-2.2%	-0.6%	-3.9%	-1.8%
	NPV	-1.3%	1.8%	0.7%	-3.8%	0.1%	1.1%	-0.2%	5.3%
	IRR	-0.8%	-2.6%	0.0%	-1.1%	-0.6%	1.7%	0.6%	4.9%
$dc \times 1.2$	Eco. imp.	2.8%	0.8%	-0.6%	2.0%	2.3%	-2.1%	1.3%	1.1%
	NPV	-1.5%	0.7%	1.0%	-2.8%	-0.1%	5.1%	-0.3%	-2.6%
	IRR	0.8%	41.9%	0.7%	-2.2%	0.6%	1.7%	0.6%	4.9%
$tr_n \times 0.9$	Eco. imp.	2.1%	-1.5%	0.1%	0.8%	0.1%	-2.1%	0.8%	1.0%
	NPV	-1.5%	3.9%	1.0%	-3.3%	0.1%	1.2%	-0.2%	0.7%
	IRR	2.5%	0.9%	-0.7%	-2.2%	-0.6%	0.0%	0.0%	3.7%
$tr_n \times 1.1$	Eco. imp.	1.8%	0.1%	2.0%	4.6%	1.1%	-0.3%	-2.2%	2.5%
	NPV	-2.4%	1.6%	-1.2%	-5.5%	-0.4%	1.6%	0.3%	-1.5%
	IRR	-0.8%	0.0%	-2.9%	-4.5%	-1.9%	0.0%	1.8%	-1.2%
$cc + 10\%$	Eco. imp.	-0.4%	0.0%	1.2%	1.1%	2.5%	1.9%	-1.4%	5.7%
	NPV	23.9%	29.5%	15.6%	29.3%	11.8%	34.6%	9.6%	33.2%
	IRR	12.7%	8.5%	3.6%	19.1%	1.9%	13.6%	0.0%	-2.4%
$be + 25\%$	Eco. imp.	4.6%	0.3%	2.8%	4.0%	3.5%	0.6%	3.3%	1.6%
$bm - 20\%$	NPV	-3.5%	0.4%	-1.5%	-4.3%	-1.5%	-2.3%	-1.5%	-0.5%
$bl - 5\%$	IRR	-2.5%	-6.8%	-2.9%	-4.5%	-1.9%	-1.7%	-1.8%	-1.2%
$be - 55\%$	Eco. imp.	-6.8%	-13.0%	-5.5%	-11.0%	-1.6%	-10.4%	-5.3%	-8.1%
$bm - 20\%$	NPV	12.4%	15.6%	10.8%	13.9%	7.5%	16.8%	6.8%	15.0%
$bl + 75\%$	IRR	16.1%	17.1%	10.9%	18.0%	12.2%	23.7%	12.3%	26.8%

5.6 Conclusion

Chapter 5 presents the simulated results concerning the physical production of beef weaners, the herd composition, economic impact and financial analysis for each scenario of a *Babesia bigemina* and *Babesia bovis* prevalence for either an intensive or strategic dipping programme. In the case of *Babesia bigemina* prevalence, the number of remaining breeding cows at year end after culling, natural and disease induced deaths have occurred in both dipping strategies for all scenarios maintains a yearly mean of 80 - 82% of the herd at year start. The proportion of the breeding cows receiving primary infections in scenarios one to four for intensive dipping averaged at 8.0%, 8.0%, 6.0% and 2.0% in each year, respectively, and the number of acute deaths occurring was <1.0%. The proportion of primary infections in each scenario differed for the strategic dipping option. In Scenario 1, it ranges from 8.0 - 5.0% in the first four years until a stable rate of 4.0% is achieved. A stable rate of 4.0% is achieved from the second year onwards before 24% of the breeding cows in the first year for Scenario 2. Scenario 3 experienced a high proportion of primary infection rates, 40% and 26%, in the first and second year, respectively. The proportion of primary infections occurring in Scenario 4 is greatest in the second year where 41% of the breeding cows fell victim. In the first and third year 23% and 15% of the cattle received a primary infection until a stability of 4.0% was realised from the fourth year onwards. The proportion of acute deaths remained below 1.0% in the

years where primary infection rates were stable at 4.0%. In years where the primary infection rate was adjusting towards stability, the proportion of acute deaths were <2.0%. Resultantly, calving and subsequent weaning rates are stable in each year for either dipping strategy. Between dipping strategies no discrepancies in calving and weaning rates occur where a yearly mean of 83% and 80% is achieved, respectively. However, the number of immune calves weaned in each scenario of the intensive dipping programme differs. In Scenarios 1 to 4, the mean proportion of immune calves weaned per year is 27%, 12%, 6.0% and 1.0%, respectively. In the strategic dipping option, the proportion of immune calves at weaning achieves a stable rate of 48% as the prevention method allows the infection rate to increase with in the breeding herd. The stable proportion of immune calves at weaning is achieved in the first year of Scenario 1 and not until the second year for Scenario 2 and 3 and in the fourth year of Scenario 4. No calves die due to acute deaths in any scenarios of either dipping strategy. In the oxen and heifer cohorts, differences in primary infections occurring for intensive and strategic dipping scenarios did not affect the number of animals reaching the sale. Yearly averages of sold weaners amongst each strategy varied between 39 - 40 oxen and 15 - 16 heifers in both dipping options for all four scenarios.

The presence of *Babesia bovis* and the resulting production effects it entails after the occurrence of a primary infection show greater damage on the breeding herd composition and the number of animals reaching the market. The proportion of breeding cows remaining at year end in Scenario 1 to 3 in the intensive dipping programme decreases from the first to the fifteenth year. An average of 77% remain in year one decreasing towards 72%, 73%, 75% in the fifteenth year for Scenarios 1, 2 and 3, respectively. However, in Scenario 4 the mean number of remaining breeding cows at year end is held constant at 80%. The end year breeding herd composition in Scenario 1 of strategic dipping is an average 75% for each year. In Scenario 2 to 4 the end year herd numbers show an increasing trend from year one where herd numbers stabilise towards an average of 76% of the number of simulated cow-spaces. However, the proportion of remaining cattle by the end of the first year were 67% and 57%, respectively. Scenario 4 differs where the number of remaining cattle decreases from 68% in the first year to 56% in the third year. From the fourth year onwards it increases again towards 67% remaining breeding cows. The augmentation of the breeding herd in both dipping options for either scenario are a result of the disease severity. In intensive dipping scenarios, the proportion of breeding cows succumbing to an acute death increases in following years due to a greater number of naive replacement heifers entering the herd. Strategic dipping scenarios show decreasing proportions of acute deaths in following years. However, the proportion of acute deaths for *Babesia bovis* are greater than that of *Babesia bigemina*. In Scenario 1 and 2 of intensive dipping similar decreasing trends in the calving rate, 80 - 76% is achieved. The weaning rate in the former scenario follows similar trends with a 5.0% decrease between the first and simulated years. The weaning rate in the latter scenario remained stable at 76%, as well as in Scenario 3. Scenario 3 and 4 of intensive dipping realised average calving rates of 79% and 82%, respectively. The weaning rate in Scenario 4 is an average 80% in each year. Calving and weaning rates amongst the scenarios of strategic dipping differ. In Scenario 1, the calving rate is held at a mean 78% and 74% for the weaning rate. Scenario 2 and 3 shows an increase in the calving rate from 71 - 79% and 63 - 79% over fifteen years, respectively. The weaning rate for each year in Scenario 2 is 77%. Scenario 3 shows the weaning rate to decline from 80 - 60% in first two years and increases towards 73% in the fifteenth year. Scenario 4 shows the calving rate decrease from 72 - 63% from the first to the third year. It then increased towards 79% in the fifteenth year. Subsequently, the weaning rate followed similar trends where it decreased from 81 - 59% in the first four years. It then increased towards 74% in the final simulated year. The virulence of a *Babesia bovis* infection affected the number of oxen and weaners reaching the sale compared with scenarios pertaining to a *Babesia bigemina*

prevalence. The mean number of weaners sold in Scenario 1 to 4 for intensive dipping each year were 33, 34, 37 and 39 oxen, and three, five, nine and 14 heifers respectively. The mean number of weaners sold in scenarios one and two for strategic dipping each year were 32 oxen and four heifers, respectively. Scenario 3 realised a decrease in oxen sold from 35 to 26 in the first two years which stabilised at a mean of 32 from the fourth year onwards, where as heifers remained at and average per year of four. Scenario 4 showed a decrease from 37 to 26 sold in the first four years. It then increased to a mean of 32 per year from the seventh year onwards. Heifer sales varied from two to five per year from the fifth year onwards. A smaller number of heifer and oxen reaching the sale are a result of a decreased weaning rate from fewer cows giving birth to a calf while challenged with *Babesia bovis* and the severity of disease imposed on young animals. Furthermore, the small number of heifers reaching the market are due to the high number of cows dying of acute deaths and the subsequent replacement heifer requirements.

The production effects of *Babesia bigemina* and *Babesia bovis* were translated into an economic impact assessment and a financial analysis of each dipping strategy per parasite prevalence. The economic impact and financial analyses of either dipping strategy and respective scenario were compared. The economic impact assessment included the sum of all discounted costs as a result of disease prevalence and severity after a primary infection had occurred in either the breeding cows, weaners and calves in each one of the fifteen simulated years. The financial analysis included all the cash in- and outflows directly related to the production of beef weaners in the face of a bovine babesiosis challenge respective of the parasite prevalence and resulting disease severity. In light of a *Babesia bigemina* infection, the economic impact in Scenario 2 to 4 were greater for strategic dipping, but less than intensive dipping in Scenario 1. The economic consequences for intensive dipping decreased by an average of R21 115.34, with a range from R15 925.43 to R23 954.69, for each decrease in seroprevalence as per the respective scenarios. Adversely, the economic impact of strategic increased with a decrease in seroprevalence. Scenario 1 incurred the lowest impact of R82 082.86 and the greatest consequence of R95 679.96 was achieved in Scenario 4. The greatest component of the economic cost in each strategic dipping scenario was the value of weight lost consisting an average of 76% in each year. Dipping and treatment costs consisted 10% and 9% in each year. The balance is consisted of recovery feed and compensatory growth costs. The value of weight lost cost component for an intensive dipping programme was greatest in Scenario 1, 2 and 3 consisting 67%, 63% and 53% of the total economic impact, respectively. This is followed by the dipping expenditure component which made up 21%, 25% and 36% of the total economic cost in each year. Dipping expenditures in Scenario 4 are greatest at 66% of the total economic cost followed by the value of weight lost at 29%. Treatment costs for Scenario 1 to three comprised 9% of the economic costs in each year and 5.0% in Scenario 4. The balance of the economic impact is consisted of recovery feed and compensatory feed costs. Results of the financial analyses for either dipping strategy and the respective scenarios indicate that the intensive prevention is a better financially viable option regardless of the parasite seroprevalence, and is indicated by the larger *NPV* and *IRR* values achieved.

The economic consequences of *Babesia bovis* are greater than that of the impacts realised due to *Babesia bigemina*. In all scenarios, the total economic cost of *Babesia bovis* is greater for strategic dipping when compared with the respective scenarios of intensive dipping. The largest cost component in strategic dipping is the value of weight lost as a result of a greater number of acute deaths and the longer duration of a recoverable infection. The value of weight lost held at an average of 95% of the total economic impact per year for either scenario of strategic dipping followed by treatment costs at 2.0%. The mean value of weight lost for intensive dipping in Scenario

1 to 3 made up 94% of the total economic cost while in Scenario 4 it is 8.0% less. Treatment costs outweighed dipping expenditures in Scenarios 1 and 2 whereas the latter component is greater than the former in Scenario 3 and 4. The economic impact realised in intensive dipping decreased by an average of R320 418.40, with a range from R244 736.00 to R362 558.30, with each decrease in seroprevalence as per the respective scenarios. Adversely, the economic impact increased from R1 255 592.16 to R1 492 277.39 with each respective decrease in seroprevalence. Despite the larger economic impact realised in all scenarios of strategic dipping, the financial analysis indicates that strategic dipping is more financially viable in Scenario 1 where a greater *NPV* is achieved. The conflict of *NPV* and *IRR* is resolved by identifying a cross-over rate of 7.891%. This indicates that strategic dipping is the more profitable prevention programme to choose while the interest rate remains below or equal to the cross-over rate and the seroprevalence of *Babesia bovis* is at 90%. In Scenario 2 to 4, intensive dipping is the more financial viable option to choose due to the greater *NPV* and *IRR* values realised.

Sensitivity analysis results indicate that the *NPV* and *IRR* are most sensitive to changes, a decrease and increase, in the beef price when challenged with either parasite. However, greater sensitivity to a change in the beef price is experienced in the face of a *Babesia bovis* challenge than that of a *Babesia bigemina*. A change in the dipping price only had an affect on the economic impact of the intensive dipping strategy concerned with *Babesia bigemina* where sensitivity increase with a decrease parasite prevalence. Net present values for both dipping strategies and parasite challenges increased as a result of an increase in the conception rate. But only the economic impact of strategic dipping concerned with *Babesia bigemina* showed increases. Weaning calves at an older age for the strategic dipping option of a *Babesia bigemina* challenge resulted in the significant sensitivity of the economic impact only. However, weaning calves at a younger age showed beneficial results where the economic impact decreased and the *NPV* and *IRR* increased for both parasite challenges of either dipping option. However, greater sensitivity is realised in the strategic dipping option showing greater changes where a decreased seroprevalence exists in the first year of the simulation.

Chapter 6

Conclusions, summary and recommendations

6.1 Conclusions

In the coming years, South African beef farmers will be required to produce more cattle in order to satisfy the increasing trends in local consumption. Furthermore, increasing production will aid the country to reverse its role as a net-importer towards becoming a net-exporter of beef. Therefore, farmers need to focus on practices which will lead towards greater production efficiencies. However, farming at optimal efficiency is not an easy task due to the many production constraints that arise separately or in combination during a given year. Such constraints can come in the form of production diseases. The farmer will then be met with a set of choices that can be made in order to manage a production disease in such a manner yielding minimal cash outflows and maximum inflows. This can be best described as cost-effective disease management. Despite the awareness of production diseases the South African agriculturalists may encounter, little economic guidance is offered. Bovine babesiosis has been labelled as one of the most economically important tick-borne diseases in South Africa and is one amongst a multitude of others. The disease has been marked with such significance due to the obvious visual damage, such as mortality, it causes. But the incurred costs as a result have not been recorded in South Africa. This study attempts to resolve this gap in the literature by exploring the economic impact a farmer may incur as a result of adopting one of two dipping strategies. Furthermore, a financial analysis of either option was conducted. In order to achieve this, a model simulating 100 *Bos indicus* cross *Bos taurus* breeding cows at the start of each year, the production activities of producing weaners for sale and the production effects of bovine babesiosis. This was done after consulting important literature pertaining to bovine babesiosis and existing economic frameworks used to assess the consequences of production diseases. The model was developed on the basis of the typical farm theory and adapted to farms existing in the KwaZulu-Natal Midlands.

Bovine babesiosis is caused by many *Babesia* parasites, but *Babesia bigemina* and *Babesia bovis* are the two most pathogenic and globally economic important. Both of these protozoan parasites exist in South Africa and their distribution is dependant of their tick vectors. The climate of the KwaZulu-Natal Midlands is well suited for the survival of both tick vectors due to the high

yearly average rainfall and summer temperatures. The introduction of *Rhipicephalus microplus* in the late 1800's has been a cause of concern to the cattle industry. Having the ability to transmit the more virulent *Babesia bovis* parasite as well as the less pathogenic *Babesia bigemina*, coupled with the capabilities of reproducing faster and at greater numbers than that of the indigenous *Rhipicephalus decoloratus* - which can only transmit the latter parasite - as well as having the potential to displace the native tick increases the risk of production losses cattle farmers may face if not managed correctly. Production losses as a result of a *Babesia* infection may result in mortality, weight loss, abortions and reduced fertility depending on the severity of disease. In the light of cases which are not sub-clinical treatment expenditure will occur. Susceptibility to an infection of either parasite is also dependent on cattle breed. *Bos indicus* and their crosses show a greater degree of resistance compared with *Bos taurus* breeds. Prevention methods exist such as the use of attenuated live blood vaccines and acaricides. The routine of acaricide application may differ from farm to farm as identified in the literature as well as method, spray-race dipping as oppose to the use of plunge pools. Endemic stability is a concept which has long been discussed as a epizootiological state which has the ability to be applied as a prevention strategy against bovine babesiosis whereby the relationship between host, parasite, vector and environment is such that clinical disease rarely or never at all occurs. Endemic stability is achieved where 81 - 100% of the herd shows positive seroprevalence results after testing. At least 75% of the calves must have received a primary infection by the age of nine months. This equates to at least 63% of the calves must have received a primary infection by the time of weaning at the age of seven months. In this study the definition of strategic dipping was redefined to fit the terminology used amongst beef farmers and veterinarians to that which best fit the description when attempting to achieve endemic stability. Furthermore, the definition of intensive dipping is also introduced.

A dynamic stochastic model was developed to facilitate an economic impact assessment and financial analysis of either dipping strategy, respective of parasite infection and at various scenarios of seroprevalence. The model is unique in the sense that it is the first which attempts to explore the feasibility of implementing less intensive dipping routines in order to promote the development of endemic stability as a control strategy. It has the ability to be applied for other typical farms in South Africa by adjusting various input parameters. However, the model is limited in it's performance due to various assumptions that had to be made during model development. The largest limitations correspond with the climatic and tick population assumptions stated in Section 4.2.4. Climatic factors play a crucial role in the life cycle of the tick vectors and thus the transmission of *Babesia* parasites. Resolving this issue would require the integration of epidemiological models, with the ability to simulate the population distribution and dispersion of the tick vectors. Added to this, transmission rates as a result of different disease interventions should interact with economic models concerned with the production of beef weaners. Further considerations include resistance build-up to acaricides in ticks. Such assumptions were made due to the difficulties occurring in the collection of data concerned with bovine babesiosis. These difficulties are shared with other impact assessments of livestock diseases. Consulting with experts in the area of study resolved data constraints and contributed to the succession of this study. The production effects of bovine babesiosis on variables such as fertility, abortion and milk production and the subsequent consequences on calf growth were disregarded since little research in relation to these factors have been conducted. Thus the lack of available data leading to the assumptions stated and omitted production variables may lead to incorrect estimates. For example a loss in cattle crop in light of abortions in one time period affects production in consecutive time periods. Emphasis is thus placed on the need for more stringent data collection routines and research efforts in order to effectively analyse the impact of various control strategies of bovine babesiosis from an economic perspective. The economic cost

component of the model in this study has been developed as a foundation for future economic research in the realm of bovine babesiosis. The cost components were developed according to the pragmatic approach of valuing diseases at the farm level suggested by Hogeveen and van der Voort (2017). Their efficiency analysis framework proposed a method to value different production disease intervention strategies but was not applicable in this study. This was due to the discrepancies in the time needed for analysis and high start up costs expected as a result of strategic dipping. This suggests the need for a framework accommodating this economic phenomena to be developed.

The economic analysis of tick-borne diseases and management strategies are largely concerned with theileriosis and the infection and treatment method administered via vaccines. Very few studies concerning the economic impact of bovine babesiosis and the feasibility of different interventions exist. The majority of studies concerned with bovine babesiosis are integrated with more than one tick-borne disease. Considering the financial returns of implementing a trivalent vaccine concerning bovine babesiosis and anaplasmosis for various situations of seroprevalence provides insight on which scenario realises the greater benefits of use. Such seroprevalence situations are similar to that of the scenarios simulated in this study in order to achieve the same insight concerning which dipping strategy would realise greater benefits. In all scenarios of either parasite prevalence, the economic impact of intensive dipping were less than the strategic option except for Scenario 1 corresponding with *Babesia bigemina*. The economic impact experienced with a *Babesia bigemina* in intensive dipping translates to R62 (R46; R84) per breeding cow per year in scenarios of 90% seroprevalence and decreases towards R20 (R15; R28) in situations of 10% seroprevalence. In strategic dipping scenarios, the economic impact increases from R55 (R38; R73) in scenarios of 90% seroprevalence to R64 (R44; R85) of 10% prevalence per breeding cow per year. The virulence of *Babesia bovis* resulted in much larger impacts per breeding cow per year where R759 (R555; R1024) and R837 (R662; R1124) are estimated in scenarios of 90% seroprevalence for intensive and strategic dipping strategies, respectively. The economic impact decreased towards R118 (R88; R164) in the intensive dipping scenario of 10% seroprevalence but increases to R995 (R755; R1355) per breeding cow per year in the same scenario of strategic dipping. This suggests that bovine babesiosis caused by primary infections of *Babesia bovis* is a far greater concern to farmers than that of *Babesia bigemina*. The greatest production losses incurred are in the form of the weight lost and mortality making up 86 - 95% of the total economic impact in instances of *Babesia bovis*. This cost component is also the largest for strategic dipping scenarios with regards to *Babesia bigemina* and scenarios of high seroprevalence for the intensive dipping option. However, as the seroprevalence decreases, dipping expenditure comprises the largest cost component for intensive dipping. Net present values and *IRR* results indicate greater feasibility for intensive dipping scenarios regarding both parasite seroprevalences except in the first scenario concerned with *Babesia bovis*. This conflict between the economic impact and the *NPV* is similarly seen in the first scenario concerned with *Babesia bigemina*. This implies that farmers should be aware of the difference between cash and non-cash related flows and consider the most efficient use of resources when confronted with production diseases. Since the economic impact is largely comprised of weight loss and mortality, fewer inputs such as feed were used in the production process and resulted in a more efficient use of resources as in the case of the first scenario concerning either parasite. The overall financial results indicate that an intensive dipping strategy is the more feasible option. This is a result of prevention and failure cost cash outflows making up a small proportion of the overall costs. The largest effect on the net cash flow is due to the revenue forgone in the form of mortality which happens at a greater scale in strategic dipping scenarios. Financial indicators were most sensitive to the change in the beef price. Altering the disease cash outflow parameters had little effect on the net cash outflows.

Biological results concerning the number of naive adult cows dying as a result of a primary infection to *Babesia bovis* are similar to the suggestion of Bock *et al.* (1997). Financial results do not correspond with the findings of Okello-Onnen *et al.* (1998) where they found dipping only once a month to be more beneficial than a routine of twice a week. However, their study was concerned with four tick-borne diseases where theileriosis was the primary concern which may contribute to the discrepancies experienced between this study and theirs. Although the cows under strategic dipping reached endemic stability at some point in time depending on the seroprevalence in the first year, the calves did not. Once the seroprevalence in the breeding herd had reached near 100%, the proportion of immune calves at the time of weaning would stabilise around 47%. In order for endemic stability to have been achieved when weaned at seven months old, at least 63% of the calves should have seroconverted. These results are attributed to the model not considering tick populations and dispersion.

Considering the limitations of this model, the overall results indicate that intensive dipping realises greater benefits when compared with the application of strategic dipping in order to promote the development of endemic stability. These benefits are increased as the seroprevalence decreases towards a 0% situation as demonstrated when *NPV* results are compared with those of a healthy farm. This suggests achieving a disease free situation by means of parasite eradication. This study does not attempt to offer economic or financial insight as to the attainment of this state. Eliminating disease through eradication will contribute to an increase in animal welfare since fewer animals will have to undergo clinical infections in order for the farmer to achieve the state of endemic stability. Current results indicate that the concept of creating endemic stability as a control strategy is not a financially viable option. It is imperative to understand that these results are inconclusive due to the lack of available data as well as the limited research efforts concerned with various production effects of the disease. This emphasises the need for a greater availability of data and the integration of epidemiological and economic modelling in order to achieve more accurate results which may economically support the concept of endemic stability. Sensitivity analysis results show a positive effect on the *NPVs* that are achieved due to calves being weaned at a younger age in the strategic dipping scenarios. This is more so than for intensive dipping, and suggests that endemic stability may be a plausible concept of control. That is because the weaners were protected by their non-specific immunity for longer before being sold. Financial results also differ with the integration of other preventive measures such as blocking and the use of attenuated live vaccines.

In conclusion, the objectives of this study have been achieved. A dynamic stochastic model was developed to simulate the economic impact of bovine babesiosis a typical beef farm of the KwaZulu-Natal Midlands would encounter where one of two dipping strategies are applied. A financial analysis of the cash in- and outflows was performed for either dipping strategy based on the data generated by the simulations. The model is offered as a foundation that can be adapted in the light that further economic research is required. The need for greater data collection and research efforts in relation to the production effects in order to realise more accurate cost estimates of bovine babesiosis and efficient interventions have been established. This study explored the financial implications of promoting the development of endemic stability as a control strategy for bovine babesiosis in veld grazing beef production systems of the KwaZulu-Natal Midlands, but results are not conclusive. Achieving estimates of greater accuracy will follow if the established needs for greater data and further research efforts are met. As a result, it has laid one of the first stepping stones in the direction of achieving a more cost-effective management of this 35 year old economic problem.

6.2 Summary

South African beef farmers will need to produce at greater efficiencies in order to meet the projected rise in demand for beef products. Bovine babesiosis has been regarded as an economically important tick-borne disease in the beef sector for at least three decades. Despite its economic importance, no economic research has been conducted. Economic insight is needed in order to implement effective and efficient intervention aiding farmers to achieve greater production efficiencies. Endemic stability has been discussed as an intervention method and has been adopted amongst the beef farmers of South Africa. No economic research has attempted to value this intervention. The main aim of this study was to explore the value of adopting a strategic dipping option in an attempt to promote the development of endemic stability compared with an intensive acaricide treatment routine. The study focused on the herd level of a typical commercial veld grazing production system in the KwaZulu-Natal Midlands. The goal of the research objective was to establish a set of principles enabling further economic and financial research to be pursued. Sub-goals such as the development of a model to estimate the economic and financial consequences of the disease; the comparison of dipping strategies; establish factors concerning available data and the need for greater data collection methods and research efforts were also set in order to achieve the primary goal.

Chapter 2 provided an overview of bovine babesiosis equipping the reader with an understanding of the disease and relative factors needed in order to develop effective intervention, as well as its complexity. The overview highlighted topics such as the distribution, habitat and the resistance cattle have to the tick vectors; the physical and transmission differences between *Babesia bigemina* and *Babesia bovis* as well as their respective life cycles; the resistance different cattle breeds show due to infection and the concept of endemic stability; clinical signs; diagnostic and treatment techniques; and the various prevention strategies implemented in practice. Certain factors introduced in this chapter were incorporated in the development of the model.

A literature review is conducted in Chapter 3. Here the international and national impact of bovine babesiosis was presented. Very few published articles providing the economic impact certain economies incur as a result of bovine babesiosis were discovered. South African cost estimates are fewer and outdated. The most recent cost estimate was presented in the form of annual babesicides. The chapter continued to explore the literature where a specific focus on the discipline of AHE was held. This uncovered existing frameworks which are used for the economic assessment of livestock production diseases. The categorisation of cost components in this study were done so according to the existing frameworks. The chapter further reviewed articles concerning the economic management of tick-borne disease. Few peer reviewed publications concerning the economic management of bovine babesiosis only exists; it is largely researched in combination with other tick-borne diseases.

The description of model development and simulation is described in Chapter 4. A dynamic stochastic model was created for a typical beef farm of the KwaZulu-Natal Midlands. The model is made of four components namely; the production, activity costs, bovine babesiosis and production effects, and preventive and failure cost components. All components were described and the various simulation scenarios of either a *Babesia bigemina* or *Babesia bovis* infection for intensive and strategic dipping options. The method describing the economic impact assessment, financial analysis and data collection are included. This chapter identified the input parameters which were adjusted in order for the sensitivity analysis to be performed. The change in parameter

values were also given.

Chapter 5 presented the results realised for each simulation. The physical results concerning the breeding herd composition and the number of animals reaching the sale were primarily presented. These results were then translated into the an economic impact assessment and financial analysis of either dipping strategy for each scenario of *Babesia* parasite seroprevalence. Overall results indicate that the intensive dipping strategy is more financially suitable. The sensitivity of outputs as a results of altering certain inputs are also presented in this chapter.

The objectives of this study were achieved. A dynamic stochastic model was developed to simulate the economic impact of bovine babesiosis a typical beef farm of the KwaZulu-Natal Midlands would incur where either an intensive or strategic dipping routine is applied. A financial analysis of the cash in- and outflows was performed for either dipping strategy based on the data generated by the simulations. The model is offered as a foundation that can be adapted where the need for further economic research prevails. The need for greater data collection and research efforts in relation to the production effects in order to realise more accurate cost estimates of bovine babesiosis and efficient interventions have been established. This study explored the financial implications of promoting the development of endemic stability as a control strategy for bovine babesiosis in veld grazing beef production systems of the KwaZulu-Natal Midlands, but results are not conclusive. Achieving estimates of greater accuracy will follow if the established needs for greater data and further research efforts are met.

6.3 Recommendations

The main question this study attempted to answer concerned the financial implications of attaining the concept of endemic stability as a control strategy for bovine babesiosis. However, through the process of conducting this study, many constraints were encountered. These were largely in the form of scarce or non-existent data. Data concerning the production effects of bovine babesiosis on *Bos indicus* cross *Bos taurus* breeds is not sufficient. Research efforts have investigated effects of the disease on certain variables such as weight loss, compensatory weight gain during recovery and are more concerned with *Bos taurus* breeds. Therefore, studies as such should be continued but more focus should be placed on the cross breeds. No studies were available concerning the effect of bovine babesiosis had on milk production and the subsequent effects it would have on calf growth, fertility and abortions. This gap in the literature should be addressed by live-stock scientists and veterinarians. Greater knowledge pertaining to the effects of these production variables will lead to better cost estimates and the promotion of various cost effective intervention strategies. Of either parasite, *Babesia bovis* should continue to be the primary researched parasite due to its greater virulence resulting in greater impacts on production.

The collection of data by farmers encountering such production effects should also be documented more strictly. Most farmers acknowledge the presence of the disease but do not document it and the resulting production effects. Such data has the ability to aid research. This, however, is a challenging task as it requires the farmer to know the current seroprevalence amongst his heard and to continuously check its status throughout the year, to maintain strong relationships with the veterinarians in the area in order to correctly diagnose a sick animal and to communicate the data between the actors effectively. This may be costly for a farmer and lead to further economic studies

researching the economic value of continuous *Babesia* seroprevalence monitoring in a herd.

This study researched two different dipping strategies differing by routine. Researching other intervention strategies such as blocking, the use of attenuated live vaccines are recommended. Long term research concerning the effectiveness of certain prevention options against ticks are also in need. Such studies will provide insight to the development of tick populations on farms and the resulting transmission of *Babesia* parasites. Data obtained from such studies will aid the much required multidisciplinary research of epidemiologists and agricultural economists.

If the development of endemic stability is promoted as an option for intervention, it raises an animal welfare question since many animals will have to undergo clinical infections and even death in order for the farmer to achieve the desired state of control. Thus creating the need for research concerning welfare impact assessments and the economic value of animal welfare. On the other hand, the financial implications of vector eradication is also required. Considerations of tick resistance acaricides are emphasised.

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Appendices

Appendix A



Figure A.1: Map of KwaZulu-Natal identifying the region of the Natal Midlands (SA Venues, 2018).

Appendix B

Table B.1: Input parameters for a *Babesia bigemina* infection ($d = 1$) in susceptible cattle 9 months and younger ($z = 1$).

Parameter	Description	Cattle breed
		<i>Bos taurus</i> / <i>Bos indicus</i>
$suc_{d,z}$	Subclinical infection	0.95
$mic_{d,z}$	Mild clinical infection	0.05
$sec_{d,z}$	Severe clinical infection	0
$acd_{d,z}$	Acute infection	0
$chd_{d,z}$	Chronic infection	0
$mrn_{d,z}$	Recovery period of mild clinical infection (min days)	1
$mrx_{d,z}$	Recovery period of mild clinical infection (max days)	2
$srn_{d,z}$	Recovery period of severe clinical infection (min days)	1
$srx_{d,z}$	Recovery period of severe clinical infection (max days)	2

Note: Input parameters were defined during the semi-structured interviews with expert veterinarians from the Mooi River Veterinary Clinic.

Table B.2: Input parameters for a *Babesia bigemina* infection ($d = 1$) in susceptible cattle older than 9 months ($z = 2$).

Parameter	Description	Cattle breed
		<i>Bos taurus</i> / <i>Bos indicus</i>
$suc_{d,z}$	Subclinical infection	0.7
$mic_{d,z}$	Mild clinical infection	0.18
$sec_{d,z}$	Severe clinical infection	0.09
$acd_{d,z}$	Acute infection	0.03
$chd_{d,z}$	Chronic infection	0
$mrn_{d,z}$	Recovery period of mild clinical infection (min days)	1
$mrxd_{d,z}$	Recovery period of mild clinical infection (max days)	2
$srn_{d,z}$	Recovery period of severe clinical infection (min days)	2
$srx_{d,z}$	Recovery period of severe clinical infection (max days)	4

Note: Input parameters were defined during the semi-structured interviews with expert veterinarians from the Mooi River Veterinary Clinic.

Appendix C

Table C.1: Input parameters for a *Babesia bovis* infection ($d = 2$) in susceptible cattle 9 months and younger ($z = 1$).

Parameter	Description	Cattle breed
		<i>Bos taurus</i> / <i>Bos indicus</i>
$suc_{d,z}$	Subclinical infection	0.9
$mic_{d,z}$	Mild clinical infection	0
$sec_{d,z}$	Severe clinical infection	0.05
$acd_{d,z}$	Acute infection	0.05
$chd_{d,z}$	Chronic infection	0
$mrn_{d,z}$	Recovery period of mild clinical infection (min days)	0
$mrx_{d,z}$	Recovery period of mild clinical infection (max days)	0
$srn_{d,z}$	Recovery period of severe clinical infection (min days)	4
$srx_{d,z}$	Recovery period of severe clinical infection (max days)	10

Note: Input parameters were defined during the semi-structured interviews with expert veterinarians from the Mooi River Veterinary Clinic.

Table C.2: Input parameters for a *Babesia bovis* infection ($d = 2$) in susceptible cattle older than 9 months ($z = 2$).

Parameter	Description	Cattle breed
		<i>Bos taurus</i> / <i>Bos indicus</i>
$suc_{d,z}$	Subclinical infection	0.1
$mic_{d,z}$	Mild clinical infection	0
$sec_{d,z}$	Severe clinical infection	0.3
$acd_{d,z}$	Acute infection	0.6
$chd_{d,z}$	Chronic infection	0
$mrn_{d,z}$	Recovery period of mild clinical infection (min days)	0
$mrx_{d,z}$	Recovery period of mild clinical infection (max days)	0
$srn_{d,z}$	Recovery period of severe clinical infection (min days)	4
$srx_{d,z}$	Recovery period of severe clinical infection (max days)	10

Note: Input parameters were defined during the semi-structured interviews with expert veterinarians from the Mooi River Veterinary Clinic.

Appendix D

Table D.1: Number of monthly dippings according to dipping strategy l .

Strategy (dip_l)	Number of dippings in month m											
	1	2	3	4	5	6	7	8	9	10	11	12
Intensive ($l = 1$)	2	2	2	2	2	2	2	0	0	1	0	1
Strategic ($l = 2$)	1	1	1	1	1	1	1	0	0	0	0	0

Note: The composition of each dipping strategy were defined during the semi-structured interviews with expert veterinarians from the Mooi River Veterinary Clinic.

Table D.2: Cost of dipping per animal in age class category k .

Parameter	Age class category k						Unit	Source
	Calf $(k = 1)$	Weaner $(k = 2)$	A $(k = 3)$	AB $(k = 4)$	B $(k = 5)$	C $(k = 6)$		
dc	0	0	1.32	1.32	1.32	1.32	ZAR/dip	MVW (2018)

Note: The cost of dipping per animal was calculated according to the recommendations of use and the average 2018 cost per unit as per Midlands Veterinary Wholesalers prices.

Appendix E

Table E.1: Cost of treatment Foray 65 ($n = 1$) per kilogram of live weight.

Parameter	Age class category k						Unit	Source
	Calf ($k = 1$)	Weaner ($k = 2$)	A ($k = 3$)	AB ($k = 4$)	B ($k = 5$)	C ($k = 6$)		
tr_n	0.1109	0.1109	0.1109	0.1109	0.1109	0.1109	ZAR/kg	MVW (2018)

Note: The cost of treatment per animal was calculated according to the recommendations of use and the average 2018 cost per unit as per Midlands Veterinary Wholesalers prices.

Table E.2: Cost of treatment Metacam ($n = 2$) per kilogram of live weight.

Parameter	Age class category k						Unit	Source
	Calf ($k = 1$)	Weaner ($k = 2$)	A ($k = 3$)	AB ($k = 4$)	B ($k = 5$)	C ($k = 6$)		
tr_n	0.2635	0.2635	0.2635	0.2635	0.2635	0.2635	ZAR/kg	MVW (2018)

Note: The cost of treatment per animal was calculated according to the recommendations of use and the average 2018 cost per unit as per Midlands Veterinary Wholesalers prices.

Appendix F

Table F.1: Feed parameters for Rainfos P9 ($f = 1$) concerning animals in age class category k .

Parameter	Age class category k						Unit	Source
	Calf ($k = 1$)	Weaner ($k = 2$)	A ($k = 3$)	AB ($k = 4$)	B ($k = 5$)	C ($k = 6$)		
$feedcost_f$	0	6.67	6.67	6.67	6.67	6.67	ZAR/kg	TWK Agri (2018)
$ADFI_f$	0	0.05	0.15	0.15	0.15	0.15	kg	
$feedmonth_f$	0	4.5	4.5	4.5	4.5	4.5	Month	

Note: Feed parameters concerning $ADFI$ for animals in age class category k were defined during the semi-structured interview with a representative of De Heus Animal Nutrition.

Table F.2: Feed parameters for Macosca Brew ($f = 2$) concerning animals in age class category k .

Parameter	Age class category k						Unit	Source
	Calf ($k = 1$)	Weaner ($k = 2$)	A ($k = 3$)	AB ($k = 4$)	B ($k = 5$)	C ($k = 6$)		
$feedcost_f$	0	0	4.50	4.50	4.50	4.50	ZAR/kg	TWK Agri (2018)
$ADFI_f$	0	0	0.12	0.12	0.12	0.12	kg	
$feedmonth_f$	0	0	4	4	4	4	Month	

Note: Feed parameters concerning $ADFI$ for animals in age class category k were defined during the semi-structured interview with a representative of De Heus Animal Nutrition.

Table F.3: Feed parameters for Bovine 50 ($f = 3$) concerning animals in age class category k .

Parameter	Age class category k						Unit	Source
	Calf ($k = 1$)	Weaner ($k = 2$)	A ($k = 3$)	AB ($k = 4$)	B ($k = 5$)	C ($k = 6$)		
$feedcost_f$	0	0	5.00	5.00	5.00	5.00	ZAR/kg	TWK Agri (2018)
$ADFI_f$	0	0	0.35	0.35	0.35	0.35	kg	
$feedmonth_f$	0	0	3.5	3.5	3.5	3.5	Month	

Note: Feed parameters concerning $ADFI$ for animals in age class category k were defined during the semi-structured interview with a representative of De Heus Animal Nutrition.

Table F.4: Feed parameters for creep feed ($f = 4$) concerning animals in age class category k .

Parameter	Age class category k						Unit	Source
	Calf ($k = 1$)	Weaner ($k = 2$)	A ($k = 3$)	AB ($k = 4$)	B ($k = 5$)	C ($k = 6$)		
$feedcost_f$	3.54	3.54	0	0	0	0	ZAR/kg	TWK Agri (2018)
$ADFI_f$	0.485	1.5	0	0	0	0	kg	
$feedmonth_f$	6	8 [*] ; 3 ^{**}	0	0	0	0	Month	

* Weaners recognised as *Xweaner*.

** Weaners recognised as *Yweaner*.

Note: Feed parameters concerning $ADFI$ for animals in age class category k were defined during the semi-structured interview with a representative of De Heus Animal Nutrition.

Table F.5: Feed parameters for pasture ($f = 5$) concerning animals in age class category k .

Parameter	Value	Unit
$plantcost$	5362.19	ZAR/ha
SR	5	weaners/ha
GP	210	Days
$feedmonth_f$	7	Month

Note: The cost of planting one hectare of pasture is estimated according to tables G.1 and G.2.

Appendix G

Table G.1: Material variable costs in relation to pasture planting.

Product	Description	kg/ha	ℓ /ha	ZAR/kg	ZAR/ℓ	ZAR/ha
Seed	Italian Ryegrass	25		49.84		1246.00
Fertilizer	434	225		6.67		1501.20
	LAN	100		3.99		398.80
Spray	Round up		3		59.19	177.56
	24D		1.5		48.85	73.28
Total						3396.48

Note: Cost figures were calculated as per TWK Agri costings (TWK Agri, 2018).

Table G.2: Operation variable costs in relation to pasture planting.

Activity	Machine/ Implement	Description	Total ZAR/hr	Activity duration				Total cost	
				Work width (m)	Work speed (km/hr)	Efficiency (%)	Duration (hr/ha)	ZAR/hr	ZAR/ha
Ploughing	Tractor	73kW; 4WD; HP	408.57	3	6	85	0.65	460.146	300.74
	Disc Plough	4 furrow	51.56						
Planting	Tractor	73kW; 4WD; HP	408.57	3	2.7	90	1.37	527.36	723.40
	Planter	4 row (0.9m) Mech	51.56						
Fertilizing	Tractor	73kW; 4WD; HP	408.57	3.2	3	90	1.16	421.19	487.48
	Distributor	Single disc, 600ℓ	51.56						
Spraying	Tractor	73kW; 4WD; HP	408.57	3.2	4	80	0.98	464.41	453.72
	Sprayer	10m boom, 800ℓ	51.56						
Total									1965.35

Note: Cost figures were calculated as per the Department of Agriculture, Forestry and Fisheries guide to machine costs (DAFF, 2018).

Appendix H

Table H.1: Weight parameters concerning animals in age class category k .

Parameter	Age class category k						Unit	Source
	Calf ($k = 1$)	Weaner ($k = 2$)	A ($k = 3$)	AB ($k = 4$)	B ($k = 5$)	C ($k = 6$)		
μW_k	64.68 [*] ; 156.33 ^{**}	212.67	314.41	345.97	402.48	482.44	kg	AAM
σW_k	11.74 [*] ; 15.11 ^{**}	25.84	72.01	86.4	73.37	93.53	kg	(2018)
$\mu Price_k$	25	32.66	27.27	22.88	20.29	18.27	ZAR/kg	

^{*} Calves recognised as Xcalf

^{**} Calves recognised as Ycalf

Appendix I

Table I.1: Average daily gains for and animal in age class category k .

Parameter	Age class category k						Unit
	Calf $(k = 1)$	Weaner $(k = 2)$	A $(k = 3)$	AB $(k = 4)$	B $(k = 5)$	C $(k = 6)$	
ADG_k	1.19	1.028	0.33	0.33	0.33	0.33	kg

Note: Figures pertaining to the average daily gains of an animal in age class category k are derived from farm records within the region of study.

Appendix J

Table J.1: Description and values of the model input parameters.

Variable/Parameter	Description	Value	Unit
s_{max}	Number of breeding seasons	8	Numeric
SY	Simulation years	15	Years
CS	Cow-spaces	100	Numeric
be	Bulled early	60	%
bm	Bulled mid	30	%
bl	Bulled late	10	%
cc	Conception rate	85	%
ca	Abortion rate	1	%
mc	Mortality rate of cow	2	%
mv	Mortality rate of calf	2	%
mw	Mortality rate of weaner	2	%
g	Gender rate	50	%
CuN	Threshold age at which cows are identified as culls	116	Month
pt	Cost of pregnancy test per herd size of 100 cows	1700	ZAR/hour